# Coal Resources of the United States, January 1, 1974

GEOLOGICAL SURVEY BULLETIN 1412

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*By* PAUL AVERITT

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*A summary of information concerning the quantity and distribution of coal in the United States. Supersedes Bulletin 1275*

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# COAL RESOURCES OF THE UNITED STATES, JANUARY 1, 1974

By Paul Averitt


## ABSTRACT

The coal resources of the United States remaining in the ground on January 1, 1974, are estimated to total 3,968 billion tons, distributed in several major categories, as shown below:

*Estimated remaining coal resources of the United States, January 1, 1974*

[Figures are for resources remaining in the ground]

| Category | Billions ($10^9$) of short tons |
|---|---|
| 1. Identified resources: | |
| A. Reserve base | 424 |
| B. Additional identified resources | 1,307 |
| C. Total identified resources | 1,731 |
| 2. Hypothetical resources: | |
| A. 0–3,000 ft overburden | 1,849 |
| B. 3,000–6,000 ft overburden | 388 |
| C. Total hypothetical resources | 2,237 |
| 3. Total remaining resources | 3,968 |

The new United States estimate is a 23-percent increase over previous estimates (Averitt, 1969, 1973), made possible by an increased program of geologic mapping, exploration, and study during the past few years by Federal and State agencies and by private industry. The new estimate is based on detailed published estimates of identified resources in individual States and on generalized estimates of additional hypothetical resources for unmapped and unexplored areas in these States.

The identified tonnage has been classified in all States according to rank. It has also been classified by thickness of overburden, degree of reliability of estimates, and thickness of beds in 21 States. Coal thus classified is well distributed in all coal provinces and represents about 60 percent of the total identified tonnage. This large classified tonnage is, therefore, reasonably representative of the total identified resources. The distribution of the classified tonnage in several meaningful categories, each expressed as a per entage of the total, is as follows: (1) 91 percent is 1,000 feet or less below the surface, (2) 43 percent is bituminous coal, (3) 33 percent is in thick beds, and (4) 24 percent is in the reserve base.

The United States contains about 25 percent of the world's identified coal resources and about 20 percent of the world's estimated total coal resources. In 1972 the United States accounted for about 19 percent of the total world production. Between 75 and 80 percent of United States production is obtained from 23 thick, continuous beds.

A comparison on a uniform Btu basis of resources of coal and other fossil fuels in the United States shows that coal constitutes 69 percent of the total estimated recoverable resources of fossil fuel, whereas petroleum and natural gas together constitute only 7

percent, and oil in oil shale—which is not currently used as a fuel—constitutes only 23 percent. The disparity between the large resources of coal and the small resources of petroleum and natural gas is sharply emphasized by the fact that in 1973 the combined production of petroleum and natural gas in the United States was 3 times that of coal.

## INTRODUCTION

Coal is widespread and abundant in most parts of the United States, and, like petroleum and natural gas, it has contributed significantly to our industrial and economic growth. Of the three fuels, coal is by far the most abundant. On the basis of an adjusted and weighted analysis of data available on resources of fossil fuel in the United States as of January 1, 1974, the recoverable resources of coal contain about 10 times more heat value than the combined recoverable resources of petroleum and natural gas. (See table 10.) This is an important relation that deserves recognition and examination.

Throughout the long period prior to the oil embargo imposed in 1973 by the Organization of Petroleum Exporting Countries (OPEC), the unit Btu costs of petroleum and natural gas were relatively low, and these fuels were more convenient to use and were more environmentally acceptable than coal. As a result, the fourfold increase in use of energy that has taken place in the United States since the mid-1930's has been met largely by an increase in use of petroleum and natural gas. The increase was accelerated after World War II by a prolonged period of industrial and economic growth and by a considerable increase both in population and in per-capita use of energy.

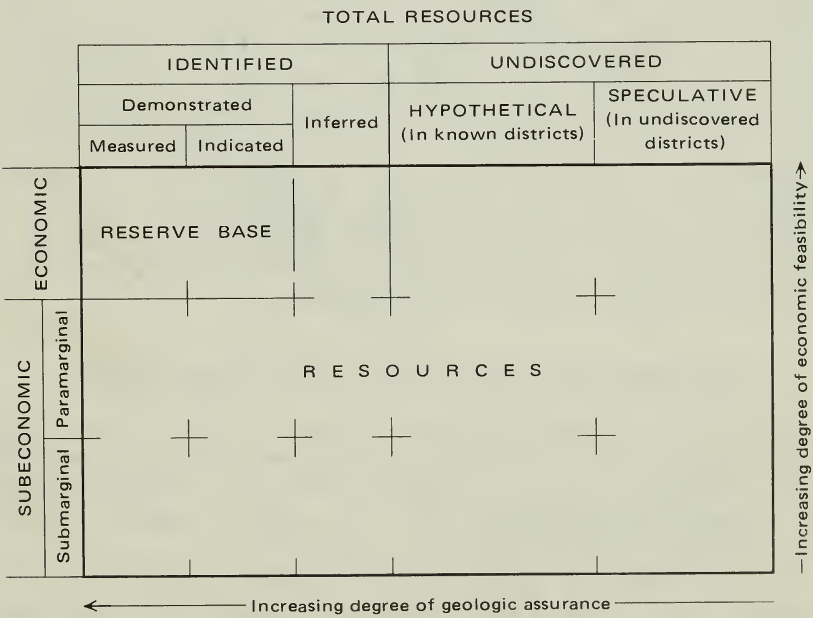
The increase in use of petroleum and natural gas was accompanied by a steady increase in net imports of petroleum beginning in the late 1950's, by an apparent decline in domestic production of petroleum, beginning in 1970, and by a sobering decline in proved reserves of both fuels beginning in the late 1960's and early 1970's. To be tested in the years ahead is the expectation that higher prices established for these fuels in 1973 and 1974 will increase domestic supply and decrease demand. The higher prices for petroleum and natural gas will surely increase use of atomic energy, coal, and other alternate sources of energy for the generation of electricity and increase use of coal, oil shale, and bituminous sands as sources of synthetic liquid fuels and pipeline gas. Use of these alternate or previously subordinate sources of energy should ease demand for petroleum and natural gas and extend the life expectancy of these premium fuels.

Although coal is widespread and abundant in the United States (figs. 1, 2), resources of coal also have limits. In the extensively mined eastern coal fields, new areas containing thick beds of high-rank and high-quality coal are becoming increasingly difficult to locate. This is particularly true for low-volatile bituminous coal, which is the most important ingredient in the manufacture of coke and which constitutes only about 1 percent of

the total resources. Furthermore, a large part of the total resources of coal in the United States consists of coal of lignite and subbituminous ranks, which yield less heat per unit weight than does bituminous coal. Another part is contained in thin beds and in deeply buried beds that can be mined only with great difficulty and expense.

The basic information on coal in the United States is contained in about 1,500 detailed geologic reports published by the U.S. Geological Survey and in a substantial and possibly equal number published by other agencies and organizations, including State Geological Surveys, the U.S. Bureau of Mines and professional societies. Additional information is contained in technical journals and in records of coal mining companies, railroads, and land-holding companies. For most States, summary reports on the geology and occurrence of coal, including estimates of coal resources, have been prepared from the detailed information in these various sources.

The present report is based in part on these State summary reports, which are cited in tables 2 and 3. It is a discussion and analysis of total United States coal resources in the broad sense, illustrated by the accompanying diagram. The resource terms used in the diagram are defined at the point of first use in the present report, and they are included in the glossary beginning on p. 105.




This report supersedes Geological Survey Bulletin 1275, which included data as of January 1, 1967 (Averitt, 1969).

### CONVERSION TO METRIC SYSTEM

In this report the main units of measurement are short tons, miles, square miles, feet, inches, and British thermal units (Btu). These and other units may be converted to the metric system by use of the following factors:

| *U.S. Units* | | *Metric System* |
|---|---|---|
| Short tons × 0.907 | = | Metric tonnes. |
| Miles × 1.609 | = | Kilometres. |
| Square miles × 2.59 | = | Square kilometres. |
| Acres × 0.4047 | = | Hectares. |
| Feet × 0.3048 | = | Metres. |
| Cubic feet × 0.0283 | = | Cubic metres. |
| Inches × 2.54 | = | Centimetres. |
| Gallons × 3.785 | = | Litres. |
| Btu × 0.252 | = | Kilogram calories. |

## ACKNOWLEDGMENTS

Many individuals have contributed substantially to the accuracy and completeness of this report by contribution and review of material on individual States and subjects. The list of these contributors includes F. F. Barnes (Alaska), H. M. Beikman (Washington), R. A. Brant (North Dakota); W. C. Culbertson and T. A. Simpson (Alabama); H. R. Collins and D. O. Johnson (Ohio); N. M. Denson, G. B. Glass, W. R. Keefer, and E. M. Schell (Wyoming); H. H. Doelling (Utah); W. E. Edmunds (Pennsylvania bituminous coal); K. J. Englund (Kentucky and Virginia); J. E. Fassett (New Mexico); S. A. Friedman (Oklahoma); B. R. Haley (Arkansas); R. D. Holt (Colorado); M. E. Hopkins and J. S. Simon (Illinois); A. L. Hornbaker (Kansas); W. R. Kaiser (Texas lignite); E. R. Landis (Iowa); E. T. Luther (Tennessee); R. S. Mason (Oregon); R. E. Matson (Montana); E. H. Montgomery (ownership of coal lands); C. E. Robertson (Missouri); and C. E. Wier (Indiana).

## DISTRIBUTION OF COAL IN THE UNITED STATES

Coal-bearing rocks underlie about 13 percent of the land area of the 50 United States and about 14 percent of the land area of the 48 conterminous States. (See figs. 1, 2; table 1; Trumbull, 1960; Barnes, 1961.) These rocks are present in 37 States, including a few, such as Illinois and West Virginia, where the coal-bearing areas represent more than half the total area of the State, and many where the coal-bearing areas represent a substantial percentage of the total areas of the State. The coal-bearing rocks range in thickness from a few hundred feet to somewhat more than 10,000 feet but, in most coal-bearing areas, are typically less than 3,000 feet in thickness.

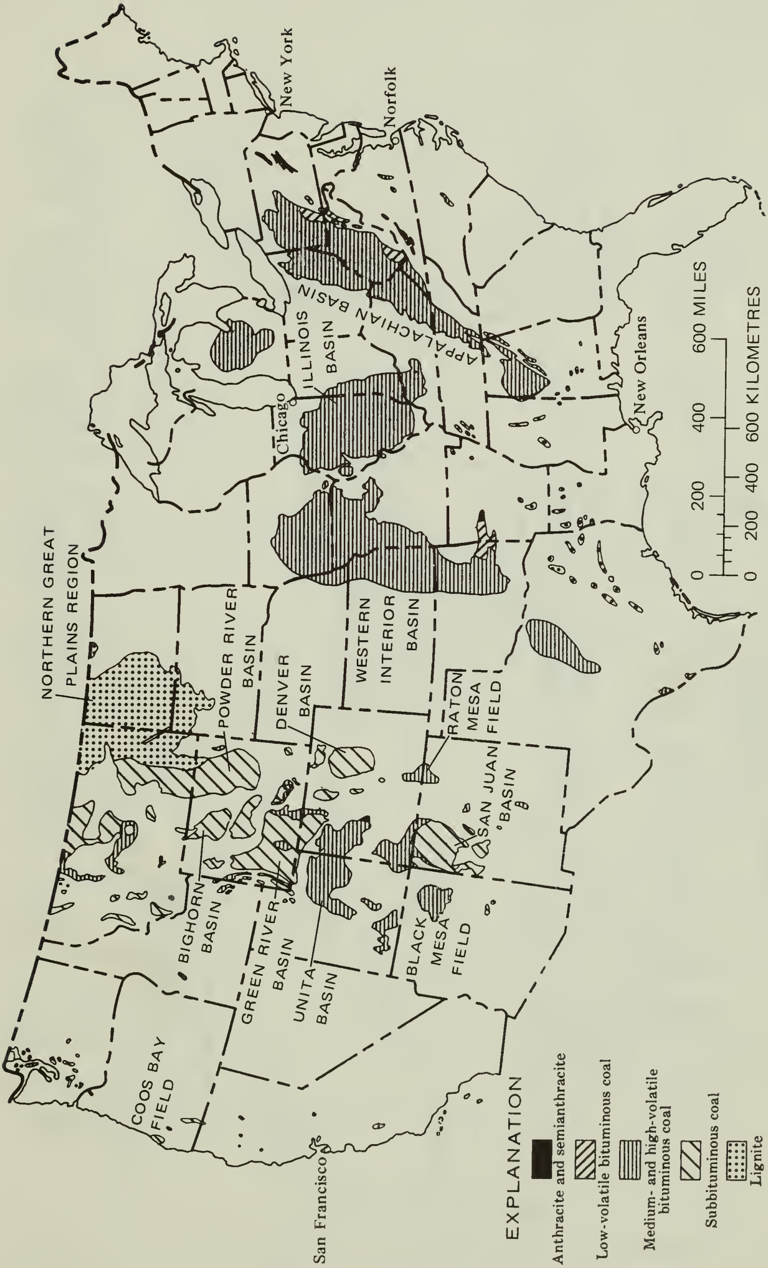



FIGURE 1.—Coal fields of the conterminous United States.

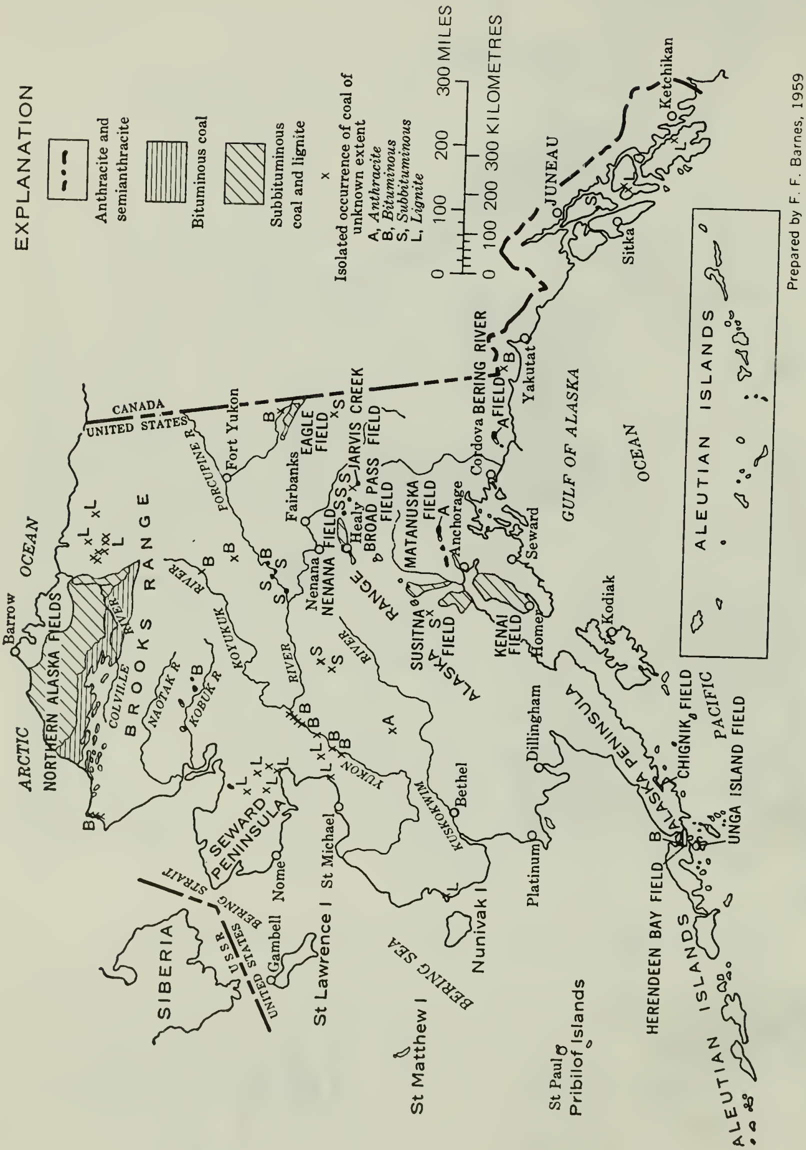



FIGURE 2.—Coal fields of Alaska.

TABLE 1.—*Size and percentage distribution of coal-bearing areas in the United States*

| State | Total area of State (sq mi)[1] | Area underlain by coal-bearing rocks | |
|---|---|---|---|
| | | Square miles | Percent |
| Alabama | 51,609 | 9,700 | 19 |
| Alaska | 586,412 | 35,000 | 6 |
| Arizona | 113,909 | 3,040 | 3 |
| Arkansas | 53,104 | 1,700 | 3 |
| California | 158,693 | 230 | .1 |
| Colorado | 104,247 | 29,600 | 28 |
| Georgia | 58,876 | 170 | .2 |
| Idaho | 83,557 | 500 | .6 |
| Illinois | 56,400 | 37,700 | 67 |
| Indiana | 36,291 | 6,500 | 18 |
| Iowa | 56,290 | 20,000 | 36 |
| Kansas | 82,264 | 18,800 | 23 |
| Kentucky | 40,395 | 14,600 | 36 |
| Louisiana | 48,523 | 1,360 | 3 |
| Maryland | 10,577 | 440 | 4 |
| Michigan | 58,216 | 11,600 | 20 |
| Mississippi | 47,716 | 1,000 | 2 |
| Missouri | 69,686 | 24,700 | 35 |
| Montana | 147,138 | 51,300 | 35 |
| Nebraska | 77,227 | 300 | .4 |
| Nevada | 110,540 | 50 | ..... |
| New Mexico | 121,666 | 14,650 | 12 |
| New York | 49,576 | 10 | ..... |
| North Carolina | 52,586 | 155 | .3 |
| North Dakota | 70,665 | 32,000 | 45 |
| Ohio | 41,222 | 10,000 | 24 |
| Oklahoma | 69,919 | 14,550 | 21 |
| Oregon | 96,981 | 600 | .6 |
| Pennsylvania | 45,333 | 15,000 | 33 |
| South Dakota | 77,047 | 7,700 | 10 |
| Tennessee | 42,244 | 4,600 | 11 |
| Texas | 267,338 | 16,100 | 6 |
| Utah | 84,916 | 15,000 | 18 |
| Virginia | 40,817 | 1,940 | 5 |
| Washington | 68,192 | 1,150 | 2 |
| West Virginia | 24,181 | 16,800 | 69 |
| Wyoming | 97,914 | 40,055 | 41 |
| Other States | 312,855 | 0 | 0 |
| United States total | 3,615,122 | 458,600 | 13 |

[1]U.S. Bureau of the Census, 1973. Statistical abstract of the United States; 94th ed., p. 172.

## NUMBER OF COAL BEDS

Coal beds are distributed irregularly, but in substantial number, throughout the sequences of coal-bearing rock. The table on page 8 shows the approximate total number of named and described coal beds, and the number of beds known to be of minable thickness in various

Eastern and Central States. The Rocky Mountain and Pacific Northwest States are not represented in the accompanying table, because the Cretaceous and younger coal beds in these States are discontinuous and overlapping, the coal occurs in isolated structural basins, and statewide correlations and nomenclature have not yet been established. However, the number of coal beds present at any one locality in the Western States is comparable to the number present at any one locality in the Eastern and Central States.

*Number of coal beds in selected Eastern and Central States*

| *State* | *Approximate number of named and described coal beds* | *Number of coal beds used in resource calculations, or known to be of minable thickness* |
|---|---|---|
| Alabama | 80+ | 41 |
| Arkansas | 19 | 4 |
| Illinois | 40+ | 20 |
| Indiana | 16+ | 16 |
| Iowa | 24 | 19 |
| Kansas | 53 | 15 |
| Kentucky (eastern) | 60 | 33 |
| Missouri | 40+ | 13 |
| North Carolina | 2 | 2 |
| Ohio | 67 | 24 |
| Oklahoma | 20+ | 18 |
| Pennsylvania | 36 | 19 |
| Tennessee | 45 | 27 |
| Virginia | 60+ | 60 |
| West Virginia | 117 | 62 |

## MAIN STRUCTURAL BASINS

In most coal-field areas, the coal-bearing rocks and the enclosed coal beds lie in structural basins, or synclines, the largest of which are broad and shallow. In the Appalachian basin, for example, the bulk of the coal is generally less than 3,000 feet below the surface. In the Eastern and Western Interior basins, the coal is generally less than 2,000 feet below the surface. In the Northern Great Plains region of eastern Montana, North Dakota, and South Dakota, all the coal is less than 1,500 feet below the surface. In the Powder River basin of northeastern Wyoming, practically all the coal to the base of the Fort Union Formation is less than 2,000 feet below the surface. In the San Juan basin of northwestern New Mexico and southwestern Colorado, the bulk of the coal is less than 4,000 feet below the surface. In the Raton Mesa field of Colorado and New Mexico, practically all the coal is less than 2,000 feet below the surface.

Other coal basins, particularly those in the Rocky Mountain region and in the Pacific Northwest, are characterized by steep dips and narrow

marginal belts of accessible coal. In the Uinta basin of Utah and Colorado, for example, the coal-bearing rocks dip steeply basinward and are more than 6,000 feet below the surface only a few miles from the outcrops. In the Green River basin of southwest Wyoming, the coal-bearing rocks are locally as much as 15,000 feet below the surface, and in the Wind River and Bighorn basins of central and northern Wyoming, they are as much as 20,000 feet below the surface.

The fact that coal-bearing rocks in the United States occur primarily in two diverse structural settings—in many large, shallow basins, and in a few very deep ones—accounts for the concentration of coal resources in the shallower overburden categories.

## COAL RESOURCES

As determined by analysis and summation of information from many sources, the remaining coal resources of the United States as of January 1, 1974, total 3,968 billion short tons, distributed in four major categories as follows:

*Estimated remaining coal resources of the United States, January 1, 1974*

[Figures are for coal remaining in the ground]

| Category | Billions ($10^9$) of short tons |
|---|---|
| 1. Identified (measured, indicated and inferred) resources: | |
| A. Reserve base (table 5) | 424 |
| B. Additional identified resources (line 1C–1A) | 1,307 |
| C. Total identified resources (table 2) | 1,731 |
| 2. Hypothetical resources: | |
| A. 0–3,000 ft overburden (table 3) | 1,849 |
| B. 3,000–6,000 ft overburden (table 3) | 388 |
| C. Total hypothetical resources (line 2A+2B) | 2,237 |
| 3. Total remaining resources (table 3) | 3,968 |

The significance of figures in this summary table, and in subsequent more detailed tables, decrease toward the digits of lower value in the right-hand columns. In a general context, the grand total of 3,968 billion tons may be expressed as 4 trillion tons with no appreciable loss of accuracy. However, the grand total of 3,968 billion tons and other totals and subtotals presented in this report have arithmetic value because they facilitate accounting, and they aid in preserving and identifying the many smaller individual figures on which they are based.

The tonnage recorded in category 1C, total identified resources, is presented in greater detail by States and by rank in table 2, and the methods and procedures used to arrive at the individual figures are described on pages 10–32. The tonnage recorded in category 1A, the reserve base, is presented by States in table 5 and discussed on page 32. The distribution of the tonnage in category 1C according to thickness of beds,

thickness of overburden, and reliability of estimates is discussed on pages 23-27. The tonnage recorded in categories 2A and 2B, hypothetical resources, are given in greater detail by States in table 3 and discussed on pages 43 and 44.

## IDENTIFIED RESOURCES

The estimate of 1,731 billion short tons for remaining identified resources as of January 1, 1974, is given by States and by ranks of coal in table 2. Most of the estimates in table 2 were obtained from summary reports on coal in the individual States, as cited in the right-hand column of the table. These reports present data on the occurrence and distribution of coal in many resource categories, and they also contain information on the stratigraphy of coal-bearing rocks and the thickness, continuity, and composition of individual coal beds. Most of them include bibliographies to sources of more detailed information. These summary reports are invaluable in the beginning or overall study of coal in any State, but they are not substitutes for the larger number of detailed reports on which they are based.

The State estimates in table 2 are based primarily on mapped coal beds and on measurements of coal thickness along the coal outcrops, supplemented by information in mine workings and drill holes downdip from the outcrops. The information is concentrated in the 0-1,000-foot overburden category but is available to greater depths in local areas.

The estimates of identified resources are, therefore, of great interest and importance for several reasons: (1) they are based firmly on factual information; (2) they include accessible coal of current economic interest, which is discussed under the heading "Reserve Base"; (3) they aid in selecting areas favorable for further exploration and development and in planning industrial expansion; and (4) they provide data from which estimates of coal in the deeper and less accessible parts of the coal basins may be obtained by extrapolation.

Based as they are on detailed information accumulated slowly by the laborious processes of mapping outcrops of coal beds and drilling holes to test coal thickness, the estimates of identified resources in table 2 are minimum estimates and are subject to increase in the future as mapping, prospecting, and development are continued.

### METHODS OF PREPARING AND REPORTING ESTIMATES

As a first step in preparing statewide estimates of identified resources, all available information is gathered and recorded on individual coal bed maps. Sources of information include publications of the U.S. Geological Survey and State geological surveys, maps and drill records of coal mining companies, information in the files of State coal mine inspectors and railroad companies, drill records of petroleum exploration companies,

TABLE 2.—*Identified coal resources of the United States, January 1, 1974*

[In millions ($10^6$) of short tons. Estimates include beds of bituminous coal and anthracite generally 14 in. or more thick, and beds of subbituminous coal and lignite generally 2½ ft or more thick, to an overburden depth of 3,000 ft. Figures are for resources in the ground. Of the reported tonnage, 91 percent is less than 1,000 ft below the surface, and most of the remainder is 1,000–2,000 ft below the surface. (See fig. 6.) Leaders (....) mean negligible, or not pertinent]

| State | Type of estimate[1] | Estimated original or remaining identified resources | Resources depleted to Jan. 1, 1974: Production[2] | Resources depleted to Jan. 1, 1974: Production plus loss in mining[3] | Remaining identified resources Jan. 1, 1974 | Source of estimate |
|---|---|---|---|---|---|---|
| **Bituminous coal** | | | | | | |
| Alabama | R–1958 | 13,754 | [4]246 | 492 | 13,262 | Culbertson (1964). |
| Alaska | Orig. | 19,429 | 8 | 16 | 19,413 | Barnes (1967). |
| Arizona | Orig. | [5]21,250 | 8 | 16 | 21,234 | Peirce and others (1970). |
| Arkansas | Orig. | 1,816 | 89 | 178 | 1,638 | Haley (1960). |
| Colorado | Orig. | 110,003 | 443 | 886 | 109,117 | Holt (1975).[6] |
| Georgia | R–1945 | 24 | .... | .... | 24 | Johnson (1946).[6] |
| Illinois | R–1972 | [7]146,255 | [4]127 | 254 | 146,001 | Hopkins and Simon (1974; written commun., 1974).[6] |
| Indiana | R–1965 | 33,238 | [4]185 | 370 | 32,868 | Wier (1973).[6] |
| Iowa | Orig. | 7,237 | 366 | 732 | 6,505 | Landis (1965). |
| Kansas | R–1957 | 18,706 | [4]19 | 38 | 18,668 | Schoewe (1958).[6] |
| Kentucky: | | | | | | |
| Eastern | Orig. | 33,440 | 2,607 | 5,214 | 28,226 | Huddle and others (1963). |
| Western | Orig. | 38,878 | 1,379 | 2,758 | 36,120 | Do. |
| Maryland | R–1950 | 1,200 | [4]24 | 48 | 1,152 | This report. |
| Michigan | Orig. | 297 | 46 | 92 | 205 | Cohee and others (1950). |
| Missouri | Orig. | [8]31,860 | 338 | 676 | 31,184 | Robertson (1971; 1973). |
| Montana | Orig. | 2,363 | 32 | 64 | 2,299 | Combo and others (1949). |
| New Mexico | Orig. | 10,948 | 100 | 200 | 10,748 | Read and others (1950). |
| North Carolina | Orig. | 112 | 1 | 2 | 110 | Reinemund (1949; 1955). |
| Ohio | Orig. | 46,488 | 2,661 | 5,322 | 41,166 | Brant and DeLong (1960).[6] |
| Oklahoma | R–1974 | 7,117 | 0 | 0 | 7,117 | Friedman (1975).[6] |
| Oregon | Orig. | 50 | .... | .... | 50 | R. S. Mason (written commun., 1965).[6] |
| Pennsylvania | R–1970 | [9]64,552 | [4]306 | 612 | 63,940 | Edmunds (1972).[6] |
| Tennessee | R–1959 | 2,748 | [4]109 | 218 | 2,530 | Luther (1959; written commun., 1965). |
| Texas | Orig. | 6,100 | 26 | 52 | 6,048 | Mapel (1967). |
| Utah | R–1971 | [10]23,216 | [4]15 | 30 | 23,186 | Doelling (1973); Doelling and Graham (1972a, b). |
| Virginia | Orig. | 11,696 | 1,240 | 2,480 | 9,216 | Andrew Brown and others (1952). |

See footnotes at end of table.

TABLE 2.—*Identified coal resources of the United States, January 1, 1974*—Continued

| State | Type of estimate[1] | Estimated original or remaining identified resources | Resources depleted to Jan. 1, 1974: Production[2] | Resources depleted to Jan. 1, 1974: Production plus loss in mining[3] | Remaining identified resources Jan. 1, 1974 | Source of estimate |
|---|---|---|---|---|---|---|
| **Bituminous coal—Continued** | | | | | | |
| Washington | R-1960 | 1,869 | [4]1 | 2 | 1,867 | Beikman and others (1961). |
| West Virginia | Orig. | 116,618 | 8,234 | 16,468 | 100,150 | Headlee and Nolting (1940). |
| Wyoming | Orig. | 13,235 | 266 | 532 | 12,703 | Berryhill and others (1950). |
| Other States[11] | Orig. | 610 | .... | .... | 610 | |
| Total | | 785,109 | 18,876 | 37,752 | 747,357 | |
| **Subbituminous coal** | | | | | | |
| Alaska | Orig. | [12]110,696 | 15 | 30 | 110,666 | Barnes (1967). |
| Arizona | Orig. | ([5]) | ... | ... | ... | Peirce and others (1970). |
| Colorado | Orig. | 19,985 | 126 | 252 | 19,733 | Holt (1975).[6] |
| Montana | Orig. | [13]177,151 | 166 | 332 | 176,819 | Combo and others (1949).[6] |
| New Mexico | Orig. | 50,801 | 81 | 162 | 50,639 | Read and others (1950).[6] |
| Oregon | Orig. | 290 | 3 | 6 | 284 | R. S. Mason, written commun., 1965.[6] |
| Utah | R-1971 | [10]173 | ... | ... | 173 | Doelling (1973). |
| Washington | R-1960 | 4,194 | [4]7 | 14 | 4,180 | Beikman and others (1961). |
| Wyoming | Orig. | [12]123,656 | 208 | 416 | 123,240 | Berryhill and others (1950); Glass (1972). |
| Other States[14] | Orig. | 40 | 4 | 8 | 32 | |
| Total | | 486,986 | 610 | 1,220 | 485,766 | |
| **Lignite** | | | | | | |
| Alabama | Orig. | [15]2,000 | .... | .... | 2,000 | Daniel (1973). |
| Alaska | Orig. | ([12]) | .... | .... | .... | Barnes (1967). |
| Arkansas | Orig. | 350 | .... | .... | 350 | Haley (1960). |
| Colorado | Orig. | 20 | .... | .... | 20 | Soister (1974). |
| Kansas | Orig. | ([16]) | .... | .... | .... | Schoewe (1952; 1958). |
| Montana | Orig. | [13]112,533 | 6 | 12 | 112,521 | Combo and others (1949).[6] |
| North Dakota | Orig. | 350.910 | 154 | 308 | 350,602 | Brant (1953). |

| | | | | | | |
|---|---|---|---|---|---|---|
| Oklahoma | Orig. | ([16]) | .... | .... | .... | Trumbull (1957). |
| South Dakota | Orig. | [17]2,187 | 1 | 2 | 2,185 | M. J. Tipton, (written commun., 1973); D. M. Brown (1952). |
| Texas | Orig. | [18]10,426 | 85 | 133 | 10,293 | Kaiser (1974). |
| Washington | R–1960 | 117 | .... | .... | 117 | Beikman and others (1961). |
| Wyoming | Orig. | ([12]) | .... | .... | .... | Berryhill and others (1950). |
| Other States[19] | Orig. | 50 | 2 | 4 | 46 | |
| Total | | 478,593 | 248 | 459 | 478,134 | |
| **Anthracite and semianthracite** | | | | | | |
| Alaska | Orig. | ([20]) | .... | .... | .... | Barnes (1951). |
| Arkansas | Orig. | 456 | 14 | 28 | 428 | Haley (1960). |
| Colorado | Orig. | 90 | 6 | 12 | 78 | Landis (1959). |
| New Mexico | Orig. | 6 | 1 | 2 | 4 | Read and others (1950). |
| Pennsylvania | R–1965 | 19,000 | [4]94 | 188 | 18,812 | Arndt and others (1968).[6] |
| Virginia | Orig. | 355 | 10 | 20 | 335 | Andrew Brown and others (1952). |
| Washington | R–1960 | 5 | .... | .... | 5 | Beikman and others (1961). |
| Total | | 19,912 | 125 | 250 | 19,662 | |
| Total all ranks | | 1,770,600 | [21]19,859 | 39,681 | 1,730,919 | |

[1]R, remaining resources in the ground as of January 1 of the year indicated; Orig., original resources in the ground before the advent of mining.

[2]Production, 1800–85, from Eavenson (1942); 1886–1923, from U.S. Geological Survey (1886–1923); 1924–72, from U.S. Bureau of Mines (Minerals Yearbooks, 1924–72); 1973, from U.S. Bureau of Mines (1974a). For a few States, production records of State coal-mine inspectors were used.

[3]With a few minor exceptions, past losses in mining assumed to equal past production.

[4]Production from year remaining resources were estimated through 1973.

[5]All tonnage is in the Black Mesa field. Some coal in the Dakota Formation is near the rank boundary between bituminous and subbitiminous coal. Does not include small resources of thin and impure coal in the Deer Creek and Pinedale fields.

[6]See other summary reports on coal resources in individual States as follows: Colorado (Hornbaker and Holt, 1973; Landis, 1959; Shomaker and Holt, 1973); Georgia (Butts and Gildersleeve, 1948; Sullivan, 1942); Illinois (Cady, 1952); Indiana (Spencer, 1953); Kansas (Abernathy and others, 1947); eastern Montana (Averitt, 1965); New Mexico (Fassett and Hinds, 1971; Shomaker and Holt, 1973); Ohio (Struble and others, 1971); Oklahoma (Trumbull, 1957); Oregon (Mason and Erwin, 1955; Mason, 1969); Pennsylvania anthracite (Ashley, 1945; Ashmead, 1926; Rothrock, 1950); Pennsylvania bituminous coal (Reese and Sisler, 1928); Texas bituminous coal (Evans, 1974); and Texas lignite (Fisher, 1963; Perkins and Lonsdale, 1955).

[7]Includes beds to a minimum thickness of 18 in. for overburden of 0–150 ft, and beds to a minimum thickness of 28 in. for overburden in excess of 150 ft.

[8]Includes 6,719 million tons in beds 12–18 in. thick. Much of this thin coal is strippable.

[9]Minimum bed thickness: Beaver, Butler, and Lawrence Counties, 14 in.; all other counties, 18 in.

[10]Excludes coal in beds less than 4 ft thick.

[11]California, Idaho, Nebraska, and Nevada.

[12]Small resources and production of lignite included with subbituminous coal.

[13]Original subbituminous coal resources of 132,151 million tons as estimated by Combo and others (1949), increased 45,000 million tons to 177,151 million tons; and original lignite resources of 87,533 million tons increased 25,000 million tons to 112,533 million tons, on basis of more recent geologic mapping and exploratory drilling in eastern Montana.

[14]California and Idaho.

[15]Single discontinuous bed 0–40 ft thick; maximum overburden, 250 ft.

[16]Small resources of lignite in western Kansas and western Oklahoma in beds generally less than 30 in. thick.

[17]Original lignite resources of 2,033 million tons as estimated by D. M. Brown (1952), increased to 2,187 million tons to accord with new data on stripping coal provided by M. J. Tipton (written commun., 1973).

[18]Overburden, 0–200 ft; lignite beds, 3–10 ft thick.

[19]California, Idaho, Louisiana, Mississippi, and Nevada.

[20]Small resources of anthracite in the Bering River field believed to be too badly crushed and faulted to be economically recoverable (Barnes, 1951).

[21]Less than total recorded cumulative production of about 42.3 billion tons. See also footnotes 1 and 4.

TABLE 3.—*Total estimated remaining coal resources of the United States, January 1, 1974*

[In millions ($10^6$) of short tons. Estimates include beds of bituminous coal and anthracite generally 14 in. or more thick, and beds of subbituminous coal and lignite generally 2½ ft or more thick, to overburden depths of 3,000 and 6,000 ft. Figures are for resources in the ground]

| State | Overburden 0–3,000 feet | | | | | | | Overburden 3,000–6,000 feet | Overburden 0–6,000 feet |
|---|---|---|---|---|---|---|---|---|---|
| | Remaining identified resources, Jan. 1, 1974 (from table 2) | | | | | | | | |
| | Bituminous coal | Subbituminous coal | Lignite | Anthracite and semianthracite | Total | Estimated hypothetical resources in unmapped and unexplored areas[1] | Estimated total identified and hypothetical resources remaining in the ground | Estimated additional hypothetical resources in deeper structural basins[1] | Estimated total identified and hypothetical resources remaining in the ground |
| Alabama | 13,262 | 0 | 2,000 | 0 | 15,262 | 20,000 | 35,262 | 6,000 | 41,262 |
| Alaska | 19,413 | 110,666 | (2) | (3) | 130,079 | 130,000 | 260,079 | 5,000 | 265,079 |
| Arizona | [4]21,234 | (4) | 0 | 0 | 21,234 | 0 | 21,234 | 0 | 21,234 |
| Arkansas | 1,638 | 0 | 350 | 428 | 2,416 | [5]4,000 | 6,416 | 0 | 6,416 |
| Colorado | 109,117 | 19,733 | 20 | 78 | 128,948 | 161,272 | 290,220 | 143,991 | 434,211 |
| Georgia | 24 | 0 | 0 | 0 | 24 | 60 | 84 | 0 | 84 |
| Illinois | 146,001 | 0 | 0 | 0 | 146,001 | 100,000 | 246,001 | 0 | 246,001 |
| Indiana | 32,868 | 0 | 0 | 0 | 32,868 | 22,000 | 54,868 | 0 | 54,868 |
| Iowa | 6,505 | 0 | 0 | 0 | 6,505 | 14,000 | 20,505 | 0 | 20,505 |
| Kansas | 18,668 | 0 | (6) | 0 | 18,668 | 4,000 | 22,668 | 0 | 22,668 |
| Kentucky: | | | | | | | | | |
| Eastern | 28,226 | 0 | 0 | 0 | 28,226 | 24,000 | 52,226 | 0 | 52,226 |
| Western | 36,120 | 0 | 0 | 0 | 36,120 | 28,000 | 64,120 | 0 | 64,120 |
| Maryland | 1,152 | 0 | 0 | 0 | 1,152 | 400 | 1,552 | 0 | 1,552 |
| Michigan | 205 | 0 | 0 | 0 | 205 | 500 | 705 | 0 | 705 |
| Missouri | 31,184 | 0 | 0 | 0 | 31,184 | 17,489 | 48,673 | 0 | 48,673 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Montana | 2,299 | 176,819 | 112,521 | 0 | 291,639 | 180,000 | 471,639 | 0 | 471,639 |
| New Mexico | 10,748 | 50,639 | 0 | 4 | 61,391 | [7]65,556 | 126,947 | 74,000 | 200,947 |
| North Carolina | 110 | 0 | 0 | 0 | 110 | 20 | 130 | 5 | 135 |
| North Dakota | 0 | 0 | 350,602 | 0 | 350,602 | 180,000 | 530,602 | 0 | 530,602 |
| Ohio | 41,166 | 0 | 0 | 0 | 41,166 | 6,152 | 47,318 | 0 | 47,318 |
| Oklahoma | 7,117 | 0 | ([6]) | 0 | 7,117 | 15,000 | 22,117 | [8]5,000 | 27,117 |
| Oregon | 50 | 284 | 0 | 0 | 334 | 100 | 434 | 0 | 434 |
| Pennsylvania | 63,940 | 0 | 0 | 18,812 | 82,752 | [9]4,000 | 86,752 | [10]3,600 | 90,352 |
| South Dakota | 0 | 0 | 2,185 | 0 | 2,185 | 1,000 | 3,185 | 0 | 3,185 |
| Tennessee | 2,530 | 0 | 0 | 0 | 2,530 | 2,000 | 4,530 | 0 | 4,530 |
| Texas | 6,048 | 0 | 10,293 | 0 | 16,341 | [11]112,100 | 128,441 | ([11]) | 128,441 |
| Utah | [12]23,186 | 173 | 0 | 0 | 23,359 | [13]22,000 | 45,359 | 35,000 | 80,359 |
| Virginia | 9,216 | 0 | 0 | 335 | 9,551 | 5,000 | 14,551 | 100 | 14,651 |
| Washington | 1,867 | 4,180 | 117 | 5 | 6,169 | 30,000 | 36,169 | 15,000 | 51,169 |
| West Virginia | 100,150 | 0 | 0 | 0 | 100,150 | 0 | 100,150 | 0 | 100,150 |
| Wyoming | 12,703 | 123,240 | ([2]) | 0 | 135,943 | 700,000 | 835,943 | 100,000 | 935,943 |
| Other States[14] | 610 | [15]32 | [16]46 | 0 | 688 | 1,000 | 1,688 | 0 | 1,688 |
| Total | 747,357 | 485,766 | 478,134 | 19,662 | 1,730,919 | 1,849,649 | 3,580,568 | 387,696 | 3,968,264 |

[1]Source of estimates: Alabama, W. C. Culbertson; Arkansas, B. R. Haley; Colorado, Holt (1975); Illinois, M. E. Hopkins and J. A. Simon; Indiana, C. E. Wier; Iowa, E. R. Landis; Kentucky, K. J. Englund; Missouri, Robertson (1971, 1973); Montana, R. E. Matson; New Mexico, Fassett and Hinds (1971); North Dakota, R. A. Brant; Ohio, H. R. Collins and D. O. Johnson from data in Struble and others (1971); Oklahoma, S. A. Friedman; Oregon, R. S. Mason; Pennsylvania anthracite, Arndt and others (1968); Pennsylvania bituminous coal, W. E. Edmunds; Tennessee, E. T. Luther: Texas lignite, Kaiser (1974); Virginia, K. J. Englund; Utah, H. H. Doelling; Washington, H. M. Beikman; Wyoming, N. M. Denson, G. B. Glass, W. R. Keefer, and E. M. Schell; remaining States, by the author.

[2]Small resources of lignite included under subbituminous coal.

[3]Small resources of anthracite in the Bering River field believed to be too badly crushed and faulted to be economically recoverable (Barnes, 1951).

[4]All tonnage is in the Black Mesa field. Some coal in the Dakota Formation is near the rank boundary between bituminous and subbituminous coal. Does not include small resources of thin and impure coal in the Deer Creek and Pinedale fields.

[5]Lignite.

[6]Small resources of lignite in western Kansas and western Oklahoma in beds generally less than 30 in. thick.

[7]After Fassett and Hinds (1971), who reported 85,222 million tons "inferred by zone" to an overburden depth of 3,000 ft in the Fruitland Formation of the San Juan basin. Their figure has been reduced by 19,666 million tons as reported by Read and others (1950) for coal in all categories also to an overburden depth of 3,000 ft in the Fruitland Formation of the San Juan basin. The figure of Read and others was based on measured surface sections and is included in the identified tonnage recorded in table 2.

[8]Includes 100 million tons inferred below 3,000 ft.

[9]Bituminous coal.

[10]Anthracite.

[11]Lignite, overburden 200–5,000 ft; identified and hypothetical resources undifferentiated. All beds assumed to be 2 ft thick, although many are thicker.

[12]Excludes coal in beds less than 4 ft thick.

[13]Includes coal in beds 14 in. or more thick, of which 15,000 million tons is in beds 4 ft or more thick.

[14]California, Idaho, Nebraska, and Nevada.

[15]California and Idaho.

[16]California, Idaho, Louisiana, and Mississippi.

records of water-well drilling companies, and, occasionally, private records obtained from individuals. To translate this information into estimates of tonnage, a series of definitions and standardized procedures must be employed.

First, two cutoff points must be established—one at the minimum thickness of coal included in the estimate and the other at the maximum thickness of overburden allowed above the coal. A very conservative estimate may include only resources in thick beds and under thin overburden—that is, resources that could be recovered profitably under current mining conditions. A more liberal estimate, on the other hand, may include thinner, more impure, and more deeply buried coal, which might be recovered in the future when more easily mined deposits have been exhausted.

Next, the specific gravity and weight of the coal must be determined or assumed, and, where the continuity of a coal bed is unknown, a method must be selected to estimate its probable extent on the basis of available outcrop, mine, or drill data.

The way in which these and other factors are treated can vary greatly with individual estimators. For this reason, an estimate of coal resources has meaning only when considered in relation to the methods used in obtaining it.

To produce reasonably uniform results in preparing coal-resource estimates, the U.S. Geological Survey has adopted a set of definitions and recommended procedures that have been followed in preparing most of the estimates in table 1. These definitions and procedures, which are discussed in the following paragraphs, were prepared jointly by members of the U.S. Geological Survey and the U.S. Bureau of Mines and include recommendations of representatives of the coal mining industry.

## CLASSIFICATION ACCORDING TO CHARACTERISTICS OF THE COAL

### Rank Of Coal

Coal is classified by rank according to percentage of fixed carbon and heat content, calculated on a mineral-matter-free basis. As shown in figure 3, the percentages of fixed carbon and the heat content, except in anthracite, increase from the lowest to the highest rank of coal as the percentages of volatile matter and moisture decrease. This change took place progressively during the slow process by which plant material deposited as peat in swamps and marshes in the geologic past was transformed into coal. The lower layers of plant material in the swamps were first compacted under successive layers of vegetation. Later, as marine or continental deposits covered the coal swamps, the accumulated weight of sediment further compressed the plant material and the increase in temperature associated with depth of burial caused a progressive decrease in the amounts of volatile matter and moisture. It has been

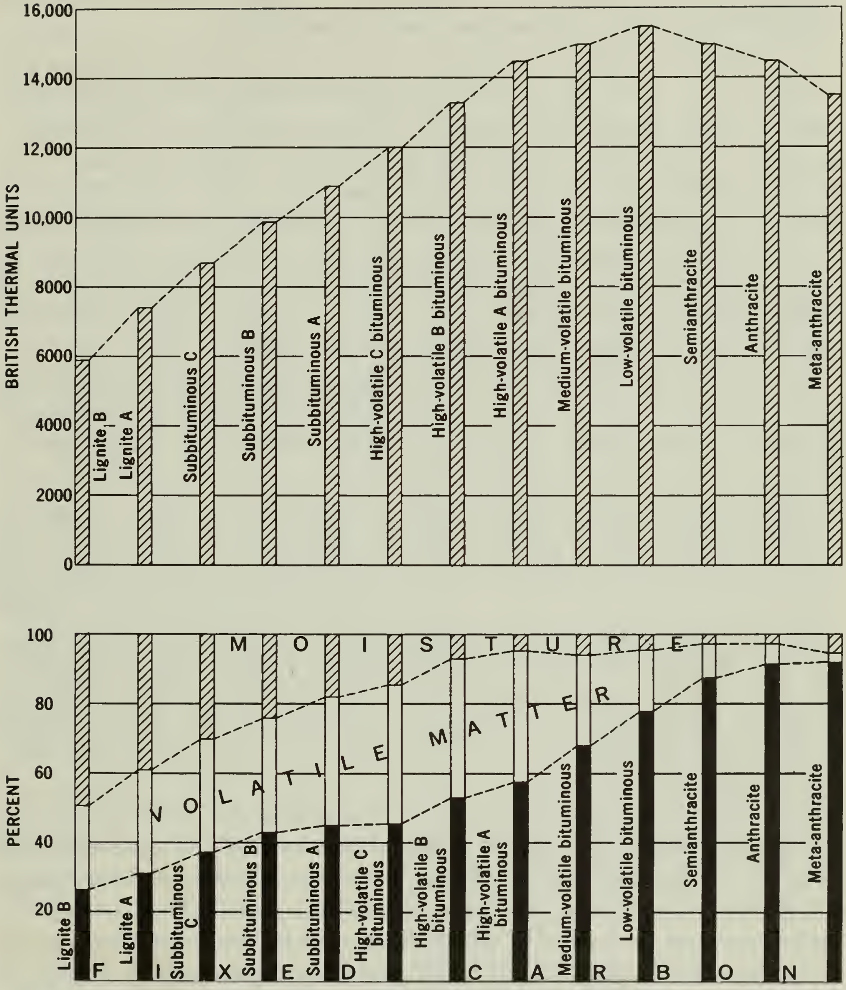



FIGURE 3.—Comparison on moist, mineral-matter-free basis of heat values and proximate analyses of coal of different ranks.

estimated that 1 foot of bituminous coal contains plant material accumulated over a period of several centuries.

The progressive devolatilization, loss of moisture, and consequent increase in rank of coal are produced by several geologic factors rated in order of decreasing importance, as follows:

1. Pressure and heat associated with depth of burial,
2. Time,
3. Structural deformation,
4. Heat of nearby intrusive igneous rocks, and
5. Plant composition and environment of coal accumulation.

These factors have been summarized and evaluated by Teichmüller and Teichmüller (1966; 1968) and by Damberger (1974).

The effects of depth of burial on rank of coal has been examined at several places. In the Ruhr coal-mining district of West Germany, where coal has been mined to a depth of 4,000 feet, the correlation between increase in rank and increase in thickness of overlying rock is well established and is used as a guide in producing the rank of coal desired by industrial consumers. In southwestern West Virginia, the increase in rank from northwest to southeast across the State was studied by Heck (1943), who concluded that a progressive northwest to southeast increase in original thickness of overlying rock (and a consequent increase in depth of burial) is the single factor of greatest importance.

The highly significant relation between depth of burial and increase in rank suggests that some Cretaceous and Tertiary coal of very high rank should be present in the deeper parts of the deep Rocky Mountain coal basins.

The effects of time on rank of coal is exhibited in a gross way by the overall distribution of coal of different rank and geologic age in the conterminous United States. As shown on a map by Trumbull (1960), coal of Pennsylvanian age in the eastern half of the conterminous United States is entirely bituminous coal and anthracite; coal of Cretaceous age in the western half of the United States is typically high-volatile C bituminous; and coal of Tertiary age, with a few exceptions attributable to structural deformation or igneous intrusion, is subbituminous coal and lignite.

The effects of structural deformation on rank are also well displayed on Trumbull's (1960) map, which shows anthracite in the complexly folded and faulted Pennsylvania anthracite fields; low-volatile bituminous coal on the east, moderately deformed edge of the Appalachian coal basin; anthracite and low-volatile bituminous coal in the folded belt of the Arkansas and Oklahoma coal fields; and bituminous coal in the tightly folded synclines of Tertiary rocks of the State of Washington. In this connection, it is perhaps worthy of mention that belts of intensely folded rock containing beds of high rank coal are usually former areas of thick geosynclinal sedimentation where deep burial could have contributed to increased rank.

The effect of large deep-seated slow-cooling igneous intrusive rocks on rank is suggested in a study of minor regional variations of rank of the Herrin (No. 6) coal in the Illinois basin by Damberger (1971). Iso-bed moisture and iso-Btu lines on the Herrin (No. 6) coal increase steadily from northwest to southeast and in most of Illinois are generally parallel to structure contour lines. In the southernmost part of the State, however, the rank increases rapidly, and is highest on the south edge of the basin. The area of this increase in rank coincides with the Illinois-Kentucky

fluorspar district, which is characterized by small outcrops of basic igneous rock, veins of fluorspar and sphalerite, and, on the basis of geophysical evidence presented by McGinnis (1970), is believed to be underlain by a deep-seated intrusive body.

Dikes and other small masses of intrusive igneous rock that locally cut across coal beds strongly affect the rank of the coal for a few feet adjoining the contact but produce no appreciable regional effects. Sills in rocks overlying coal beds likewise produce no appreciable regional effects, but sills in rocks underlying coal beds produce very pronounced regional effects, depending in intensity on the thickness of the sill and its distance from the coal bed. Examples of sills in rocks underlying coal beds, and even intruding coal beds, are well displayed on a regional scale in the Raton Mesa field of Colorado and New Mexico. (See Dutcher and others, 1966; Crelling and Dutcher, 1968.)

The effects of coal composition and the environment of coal accumulation on rank are small but are factors in explaining local borderline differences in rank. Elsewhere, the effects of coal composition and the environment of coal accumulation on rank are likely to be obscured by the larger effects of depth of burial, time, structural deformation, and heat of nearby intrusive igneous rocks.

At several places in the United States, local wide variations in rank of coal have received careful detailed study. In the Crested Butte district, Gunnison and Pitkin Counties, Colo., where coal of Cretaceous age ranges in rank from high-volatile bituminous to anthracite, Dapples (1939) presented evidence on the relative effects of depth of burial, of heat from nearby intrusive masses, and of local structural deformation in producing the observed differences. On the west side of this complexly disturbed area, a deeply buried deposit of high-rank and high-quality coking coal has been delineated by Toenges and others (1952). In the Cook Inlet basin, Alaska, where coal of Tertiary age ranges in rank from lignite to anthracite, Barnes (1962) presented quantitative data on depth of burial and regional metamorphism to account for the observed differences.

Rank is thus established as a very sensitive indicator of progressive metamorphic change throughout the coal-forming process. It is quite independent of grade or quality, which is a function of the amount of ash, sulfur, and other deleterious substances in the coal.

The standard classification of coal by rank in use in the United States is that established by the American Society for Testing and Materials (1974). This classification, which is shown in table 4, is used uniformly in classifying all coal-resource estimates. As coals of different rank are adaptable to different uses, rank is the major basis of differentiation used in tables 2 and 3, and in figures 3 and 5*A*.

Most of the tables and illustrations in this report show resources of all ranks of coal in short tons. In terms of ultimate usefulness, however, comparison of the resources of lignite and subbituminous coal, which

TABLE 4.—*Classification of coals by rank*

[This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon, or have more than 15,500 British thermal units per pound, calculated on the moist, mineral-matter-free basis. Modified from American Society for Testing and Materials (1974)]

| Class | Group | Fixed carbon limits, in percent (Dry, mineral-matter-free basis) | | Volatile matter limits, in percent (Dry, mineral-matter-free basis) | | Calorific value limits, in Btu per pound (Moist, mineral-matter-free basis)[1] | | Agglomerating character |
|---|---|---|---|---|---|---|---|---|
| | | Equal or greater than | Less than | Equal or greater than | Less than | Equal or greater than | Less than | |
| I. Anthracitic | 1. Meta-anthracite | 98 | | | 2 | | | Nonagglomerating.[2] |
| | 2. Anthracite | 92 | 98 | 2 | 8 | | | |
| | 3. Semianthracite | 86 | 92 | 8 | 14 | | | |
| II. Bituminous | 1. Low-volatile bituminous coal | 78 | 86 | 14 | 22 | | | Commonly, agglomerating.[4] |
| | 2. Medium-volatile bituminous coal | 69 | 78 | 22 | 31 | | | |
| | 3. High-volatile *A* bituminous coal | | 69 | 31 | | [3] 14,000 | | |
| | 4. High-volatile *B* bituminous coal | | | | | [3] 13,000 | 14,000 | |
| | 5. High-volatile *C* bituminous coal | | | | | 11,500 | 13,000 | |
| | | | | | | 10,500 | 11,500 | Agglomerating. |
| III. Subbituminous | 1. Subbituminous *A* coal | | | | | 10,500 | 11,500 | Nonagglomerating. |
| | 2. Subbituminous *B* coal | | | | | 9,500 | 10,500 | |
| | 3. Subbituminous *C* coal | | | | | 8,300 | 9,500 | |
| IV. Lignitic | 1. Lignite *A* | | | | | 6,300 | 8,300 | |
| | 2. Lignite *B* | | | | | | 6,300 | |

[1] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.
[2] If agglomerating, classify in low-volatile group of the bituminous class.
[3] Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.
[4] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in the high-volatile *C* bituminous group.

have relatively low heat values, with resources of bituminous coal and anthracite, which have higher heat values, can best be made on a uniform Btu basis. Such a comparison is presented in figure 4, which shows the remaining resources in each State as of January 1, 1974, on both a tonnage basis and a Btu basis.

### Grade Of Coal

Coal is classified by grade, or quality, largely according to the content of ash, sulfur, and other deleterious constituents. Thus far in work on coal resources, it has not been possible to report on resources in categories according to grade because most coal analyses are for samples from areas of active mining, or from a few thick, continuous, and well-exposed beds.

Although the definitions and procedures used in calculating coal resources generally permit the inclusion of beds containing as much as 33 percent ash, very little coal of such high ash content is included in modern estimates, in part because of the natural conservatism of the estimators, and in part because all layers of parting and bone more than three-eighths of an inch thick are excluded in determining the thickness of the beds. On the other hand, resource estimates obviously include beds containing higher ash and sulfur contents than most beds now being actively mined.

Fieldner, Rice, and Moran (1942) published a very useful and informative list of 642 typical mine, tipple, and delivered samples of coal from beds in all parts of the United States. In these samples the ash content ranged from 2.5 to 32.6 percent and averaged 8.9 percent. The sulfur content ranged from 0.3 to 7.7 percent and averaged 1.9 percent.

The maximum ash and sulfur contents of beds included in the estimated resources are probably about the same as the maximum figures shown in the list of typical analyzed samples, whereas the average ash and sulfur contents of the estimated resources are probably higher than the averages derived from the list.

### Specific Gravity Of Coal

The specific gravity of coal varies appreciably with rank and with differences in ash content. The following values, however, conform closely to the average specific gravities of unbroken coal in the ground in each of the four major rank categories and are used in preparing most estimates of coal resources.

*Specific gravity and weight of coal of different ranks*

| Rank | Coal in the ground | | |
|---|---|---|---|
| | Specific gravity | Tons per acre-foot | Tons per square-mile-foot |
| Anthracite and semianthracite | 1.47 | 2,000 | 1,280,000 |
| Bituminous coal | 1.32 | 1,800 | 1,152,000 |
| Subbituminous coal | 1.30 | 1,770 | 1,132,560 |
| Lignite | 1.29 | 1,750 | 1,120,000 |

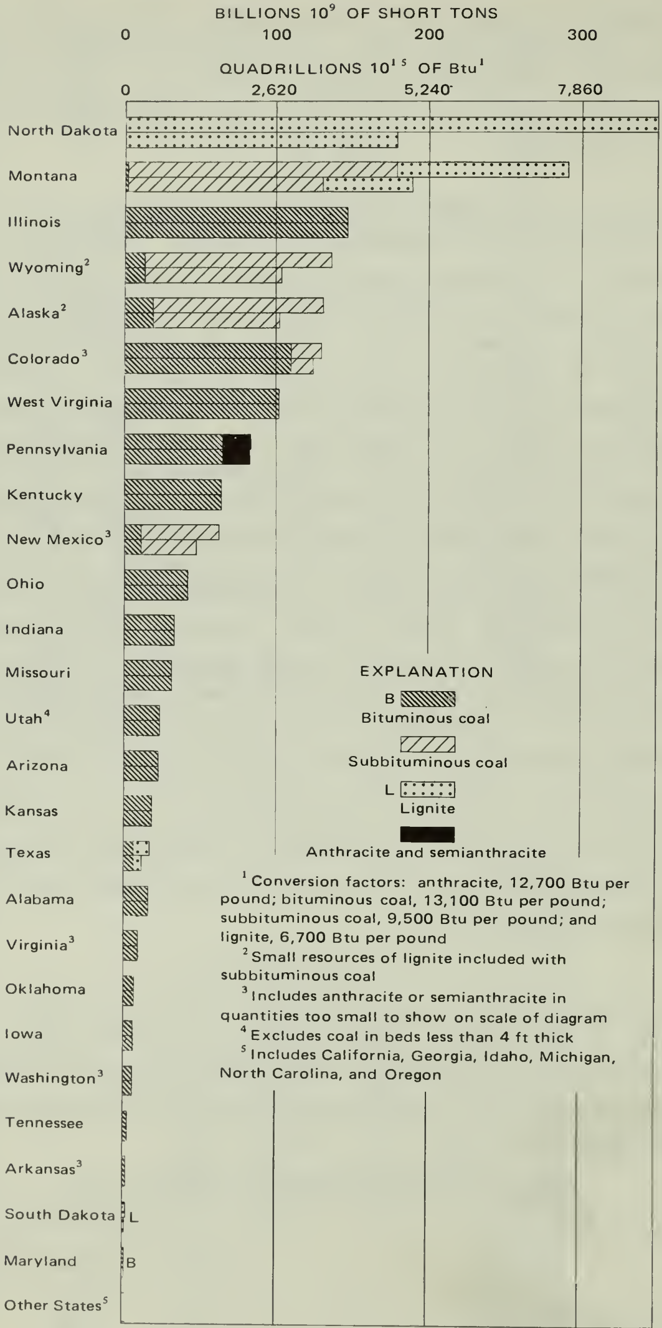



FIGURE 4.—Remaining identified coal resources of the United States, January 1, 1974, by States, according to tonnage (upper bar) and heat value (lower bar).

Persons closely associated with individual mining operations may employ lower weight factors to allow for anticipated future losses in mining. Such a practice, although suitable for discussion of a specific mine area, is not suitable for use in a general report covering many areas, because recoverability may vary greatly in different areas, in different beds, and with different methods of mining.

### Thickness Of Beds

According to the recommended procedures of the U.S. Geological Survey, coal resources should be calculated and reported by beds in three categories of thickness as follows:

*Categories of bed thickness used in calculating resources of coal of different ranks*

| Rank | Categories of bed thickness | | |
|---|---|---|---|
| | Thin | Intermediate | Thick |
| Anthracite, semianthracite, and bituminous coal (in.) | 14–28 | 28–42 | >42 |
| Subbituminous coal and lignite (ft) | 2½–5 | 5–10 | >10 |

The categories of bed thickness selected for anthracite and bituminous coal conform with present mining practices and with past procedures in estimating resources. The 14- to 28-inch category represents coal that is of little present economic interest, except for small-scale local strip and auger mining. The category is retained, however, because (1) as noted above, some coal in this category is recovered; (2) prudence dictates that occurrences of marginal resources of coal should be recorded for possible future use, just as marginal resources of other useful minerals are recorded; (3) the information is obtained with little additional effort during work with the thicker coals, and it aids in studies of coal-bed continuity and correlation; and (4) the minimum of 14 inches permits comparison with older estimates, which generally used the same figure.

The 28- to 42-inch category represents coal that can be mined using especially designed underground mechanical loading machinery.

The category of more than 42 inches represents coal that can be mined by all types of mechanical cutting and loading machinery.

As noted in the table, beds of subbituminous coal and lignite used in the three thickness categories are thicker than beds of bituminous coal and anthracite. This difference conforms with occurrences of subbituminous coal and lignite and with present interest in such coal.

In a few States the categories of bed thickness and the minimum bed thicknesses selected for use differ from the recommended standards. In Montana the categories of bed thickness used for bituminous coal are 14–24 inches, 24–36 inches, and more than 36 inches, whereas in North Carolina the categories are 14–28 inches, 28–36 inches, and more than 36 inches. In Ohio the categories are 14–28 inches, 28–54 inches, and more

than 54 inches. In Illinois a minimum bed thickness of 18 inches was used for bituminous coal to a maximum overburden depth of 150 feet, and a minimum of 28 inches was used for overburden in excess of 150 feet. In Kansas a minimum bed thickness of 16 inches was used for bituminous coal to a maximum overburden depth of 100 feet; a thickness of 18 inches, to a depth of 150 feet; 22 inches, to 200 feet; 32 inches, to 600 feet; and 36 inches, to 1,200 feet. In Missouri a minimum bed thickness of 12 inches was used.

The average thickness of coal beds used in coal-resource calculations is determined in two ways. Where information on thickness is abundant and points of information are evenly spaced, lines of equal coal thickness are drawn and used to determine the average thickness. Where information on thickness is less abundant and points of information are unevenly spaced, weighted average figures are used. The weighting is accomplished by assigning intermediate values for the thickness at points where information is needed to fill out a system of evenly spaced points. Both the direct measurements and the assigned values are then used to determine a simple average thickness. Where this procedure is followed to obtain the weighted average thickness along the outcrop of a persistent bed, the two end points of minimum thickness are included in the average.

Partings more than three-eighths of an inch thick are disregarded in determining the thickness of individual beds. Beds and parts of beds made up of alternating layers of thin coal and partings are omitted if the partings make up more than half the total thickness or if the ash content exceeds 33 percent. Benches of coal of less than the minimum thickness stated, which lie above or below thick partings and which normally would be left in mining, are also omitted.

Occasionally, in older coal-resource estimates, a formula termed "the modulus of irregularity" was used to determine the probable minimum thickness of a coal bed. According to this formula, the probable minimum thickness is obtained by multiplying the average of the measurements of bed thickness by $1-SD/S$, in which $S$ is the sum of all the thickness measurements and $SD$ is the sum of the differences between each individual thickness measurement and the average of all the thickness measurements.

The modulus of irregularity was originally adopted by the U.S. Geological Survey as a mechanism in establishing the value of coal lands (Smith and others, 1913, p. 88), but it is no longer used for this purpose. It was devised as a safeguard for the buyer of coal lands in areas where the coal beds vary widely in thickness. As stated by Smith and others (1913), computation of the thickness of the coal by using the modulus of irregularity permitted the "thickness of the coal under any tract of land to be considered as less than the average of the measurements. For while the coal is as likely to be just above the average as just below, and mathematically, is more likely to be just the average thickness than any

other, yet a cautious buyer bargaining for coal would always want to discount the probability a little as a matter of safety." The modulus of irregularity is no longer used in preparing estimates of coal resources.

### Areal Extent Of Beds

The areal extent of coal beds included in modern classified coal-resource estimates is determined in several ways. Where the continuity of a bed is well established from maps of the outcrop, from mine workings, and from drill holes, the entire area of the known occurrence of the bed is taken, even though points of observation are widely spaced. Persistent beds that have been traced around a basin or spur are assumed to underlie the area enclosed by the outcrop. Otherwise, the length of outcrop within the thickness limits listed is assumed to determine the presence of coal in a semicircular area, having a radius equal to half the length of the outcrop. The total area of coal is considered to extend beyond such a semicircle if mine workings or drill holes so indicate; in which case, coal is assumed to extend no more than 1 mile beyond the limiting point of information. An isolated drill hole farther from the area thus defined is assumed to determine the area of coal extending for a maximum radius of one-half mile around the hole.

These conservative procedures have been followed in preparing most of the estimates presented in table 2.

### Thickness Of Overburden

Wherever possible, coal-resource data are divided into three major categories according to thickness of overburden, in feet, as follows: 0–1,000, 1,000–2,000, and 2,000–3,000. In a few States where the overburden is thin, the resources have been calculated in several subcategories within the 0- to 1,000-foot category; and in others, where the overburden is thicker or where information is inadequate, one or more of the major categories may be combined.

In Arkansas the resources are divided into five categories according to the thickness of overburden, in feet, as follows: 0–60, 60–500, 500–1,000, 1,000–2,000, and 2,000–3,000.

In Michigan, where all the coal is less than 400 feet below the surface, the resources are divided into four categories according to thickness of overburden, in feet, as follows: 50–100, 100–200, 200–300, and 300–400.

In other States, no overburden categories were employed, but in each of these States the coal included in the identified category is 2,000 feet or less below the surface, as shown in the following table:

*Maximum overburden, in feet, on coal included in estimates of identified resources in States where overburden categories were not employed*

| *State* | *Maximum overburden* | *State* | *Maximum overburden* |
|---|---|---|---|
| Arizona | 1,700 | Indiana | <1,000 |
| Illinois | 2,000 | Iowa | 1,000 |

*Maximum overburden, in feet, on coal included in estimates of identified resources in States where overburden categories were not employed*—Continued

| State | Maximum overburden | State | Maximum overburden |
|---|---|---|---|
| Kansas | 1,200 | Ohio | 1,000 |
| Kentucky | >1,000 | South Dakota | <1,000 |
| Missouri | 1,500 | Tennessee | 2,000 |
| Montana | 2,000 | Virginia | >1,000 |
| North Dakota | 1,200 | | |

In some of these States coal occurs at depths somewhat greater than those shown, but is not included in estimates of identified resources.

## CLASSIFICATION ACCORDING TO RELIABILITY OF ESTIMATES

Wherever possible, coal-resource estimates are divided into three categories according to the relative abundance and reliability of data used in preparing the estimates. These categories are termed "measured," "indicated," and "inferred."

### Measured Resources

Estimates of measured resources are based on individual mapped coal beds for which the thickness and continuity are determined by observations in natural exposures along outcrops, and in trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced, and the thickness and extent of the coal beds so closely defined, that the computed tonnage is judged to be accurate within 20 percent of the true tonnage. Although the spacing of points of information necessary to demonstrate continuity of a coal bed at the "measured resource" confidence level differs from region to region according to the character of the coal beds, the points of observation are about one-half mile apart.

Measured resources constitute only part of a coal bed, and the additional tonnage present is classed as indicated or as indicated and inferred.

### Indicated Resources

Estimates of indicated resources are also based on individual mapped coal beds and are computed in the same way as measured resources. In general, however, the points of observation and measurement used to compute indicated resources are more widely spaced, and the continuity and thickness of the beds are projected over longer distances on the basis of geologic evidence. At the "indicated resource" confidence level, the points of observation and measurement are about 1 mile apart, but they may be as much as 1½ miles apart for beds of known continuity. For example, a block of indicated coal is established by measurements of thickness and evidence of continuity at intervals of 1 to 1½ miles along the outcrop and by drill holes at the same spacing downdip from the outcrop. Or, if closely

spaced measurements on an individual bed permit computation of measured resources in a zone one-half mile wide along the outcrop, then the indicated resources in the same bed tend to lie behind the zone of measured resources in a subparallel zone at least 1½ miles wide, or wider, if confirming drill-hole information is available.

#### Demonstrated Resources

In several States—particularly Alabama, Colorado, Iowa, Montana, and Washington—where the amount of measured resources is comparatively small, the measured and indicated categories were combined in a single category requiring only a single computation. When this procedure is followed, or when tonnages in the measured and indicated categories as defined above are combined, the term "demonstrated resources" refers to the total tonnage in the two categories.

#### Inferred Resources

Estimates of inferred resources are based primarily on an assumed continuity of coal beds into more remote areas that are downdip from and behind areas containing measured and indicated resources. Although few observations of bed thickness or proof of continuity are available in areas of inferred resources, thickness and continuity can be estimated with reasonable confidence from knowledge of the geologic character of the coal bed, the enclosing rocks, and the region in which they occur. Most coal classed as inferred lies 2 miles or more from a mapped outcrop or from points of precise information. (See "Areal Extent of Beds," p. 25.)

#### Unclassified Resources

In a few States, particularly Georgia, Maryland, Pennsylvania, and West Virginia, the resource figures presented are not divided into the measured, indicated and inferred categories and, therefore, represent most closely "identified resources" as that term is used in this report.

### DISTINCTION BETWEEN ORIGINAL, REMAINING, AND RECOVERABLE RESOURCES

Coal resources may be calculated and presented according to one or all of three different points of view as defined below.

#### Original Resources

Original resources are resources in the ground before the beginning of mining. Although subject to revision with new mapping and exploration, an estimate of original resources needs no date nor explanation to make it understandable. From this estimate the figures for remaining and recoverable resources, which must be dated, can be determined annually, if desired, from available information on production and losses or from surveys of mined-out areas.

All older estimates and most modern estimates, particularly those for Western States where relatively little mining has been done, are for original resources.

### Remaining Resources

Remaining resources are unmined resources remaining in the ground as of the date of the estimate. Where adequate records have been kept of mined-out areas, estimates of remaining resources can be calculated directly by excluding mined-out areas in the preparation of coal-bed maps. Estimates for Alabama, Georgia, Illinois, Indiana, Kansas, Maryland, Pennsylvania, Tennessee, Utah, and Washington have been made on this basis. Where records of mined-out areas are not available, remaining resources can be calculated by subtracting past cumulative production and estimated losses in mining from original resources.

In tables 2 and 3, all estimates have been reduced by the amount of production and assumed losses from the dates of the estimates to January 1, 1974, so that figures in the remaining resources columns are on a comparable basis.

### Recoverable Resources

Recoverable resources are the part of remaining resources in the ground that can be produced by appropriate effort, expenditure, and ingenuity. Coal in thick beds near the surface can be mined at or near present costs, measured in man-hours and equipment. Coal in thinner, more deeply buried beds can be mined either at an increased cost according to present mining technology, or possibly with a lesser increase in cost, or even a lower cost, according to a future improved mining technology. Coal in beds of minimum thickness, or in the deeper overburden categories, obviously cannot be regarded as recoverable by present or near-future economic standards.

The average recoverability in all past coal mining in the United States is about 50 percent, as discussion under the next heading will show. The recoverability in future mining may equal or exceed that of past mining for many years because (1) much coal in thick, accessible beds is still available for mining; (2) much coal is within reach by strip and auger mining methods; (3) the longwall and related methods of underground mining and the higher recoverability made possible by such methods may come into more widespread use; and (4) technologic improvements in underground recovery methods, as yet unforeseen, could be developed.

Recoverability in the more distant future could be reduced and mining made more expensive by problems inherent in mining thin beds, very thick beds, deeply buried beds, and (or) beds damaged by prior mining of underlying beds. On the other hand, experience with most commodities has shown very appreciable long-term changes in the average grade mined, the price, and the methods of recovery; hence, over the very long term, coal is likely to follow an analogous pattern.

For these varied reasons, it is not desirable to report coal resource data on an arbitrary recoverable basis. In keeping with this viewpoint, the figures in tables 2 and 3, and those in subsequent tables and diagrams, express original or remaining coal resources in the ground, which are more certain values that can be modified now or in the future by any recoverability factors deemed appropriate.

The coal reserve base, and economically recoverable reserves, which in the present economy represent only a small part of total coal resources, are discussed in subsequent paragraphs.

### PERCENTAGE OF COAL RECOVERED IN PAST MINING

Most studies of recoverability in past coal mining are based on comparisons between amount of coal produced and amount of coal originally present, or the amount left behind, in the block of ground being studied. These comparisons require coal production records and maps of individual mines; for this reason comparisons are generally focused on the performance of an individual mine or on mines under ownership of an individual company. Such studies usually show a higher percentage recoverability than the expectable recoverability on a broader regional or national basis. However, several regional studies of recoverability have been made, and several individuals with long experience in the coal-mining industry have provided subjective opinions on recoverability that are of interpretative value. This information is summarized under separate headings that follow.

#### Underground Mining

In a special study of the No. 6 coal bed in Franklin County, Ill., Cady (1949, p. 67–69) determined that, when barrier pillars and coal left to protect oil and gas wells are taken into account, underground mining operations to the date of his study had recovered only 33–35 percent of the coal originally present in the mined areas.

In a similar study in Perry County, Ohio, Flint (1951, p. 100) calculated that during 1938–48 the recovery from all beds was only 43 percent of the coal originally present in the mined areas.

In Michigan the recovery of coal has averaged about 60 percent of the total in the ground, according to estimates by individuals familiar with mining operations in the State (Cohee and others, 1950, p. 5).

In Utah past recovery in underground mining operations in all beds has resulted in recovery not exceeding 50 percent, according to B. W. Dyer (oral commun., 1949).

Eavenson (1946) has estimated that the actual recovery from the Pittsburgh bed in Pennsylvania is no more than 50–60 percent because of the large amount of coal that is left in barrier pillars, in reservations for oil and gas wells, under buildings, and in the rider above the main bed. In

calculating the remaining resources of bituminous coal in Pennsylvania, Ashley (1944, p. 79–83) assumed a past recovery of 50 percent for all coal in the State with the exception of that in the Pittsburgh bed, for which he assumed a recovery of 66.6 percent. Ashley's figures were based on the percentage recovery of coal in Fayette County, Pa., as determined by Moyer (Hickok and Moyer, 1940, p. 359, 417–420).

The weighted averages of recovery in mining bituminous coal in 44 counties in the Appalachian region, as determined by the U.S. Bureau of Mines, ranged from 45.4 to 65.4 percent and averaged about 54 percent (Dowd and others, 1950–52c, 1955–56; Wallace and others, 1952–55b; Williams and others, 1954–56; Hershey and others, 1955–56a, b; Blaylock and others, 1955, 1956; Travis and others, 1956; Lowe and others, 1956; Provost and others, 1956; Tavenner and others, 1956).

In a recent study of Oklahoma coal resources, Friedman (1975, p. 18, 47) determined that average recovery in all past mining operations has been only 41 percent. This is in close accord with a previous study by Trumbull (1957, p. 367), who estimated on the basis of data then available that past recovery averaged 39 percent.

In Washington, Beikman, Gower, and Dana (1961, p. 4) estimated that recoverability in past mining operations in southwest Washington averaged about 40 percent. In the Roslyn field, however, recoverability averaged about 80 percent.

In a very careful study of 200 selected underground mines, which in 1963 accounted for nearly half of the Nation's underground production of bituminous coal, Lowrie (1968, p. 14) concluded that the recovery within the mined areas ranged from 29 to 91 percent and averaged 57 percent. In all these mines overburden was less than 1,000 feet.

A considerable amount of the raw coal and associated impure partings recovered in mining is ultimately lost in the process of mechanical cleaning. In 1972, for example, 67 percent of the raw bituminous coal and lignite produced was cleaned mechanically, and an average of 26.5 percent of this amount was discarded as refuse (U.S. Bureau of Mines Minerals Yearbook 1972, p. 44).

In the studies summarized above, the median recovery is about 50 percent. It should be noted, however, that these studies do not uniformly take into account coal left in barrier pillars; in restricted areas around oil and gas wells and fields; under towns, railroads, highways, streams and reservoirs; in top and lower benches, rider beds; and in local areas of faulting and folding. None takes into account coal in higher, unmined beds damaged by prior mining of lower beds, and none takes into account coal lost in the cleaning process. For these reasons, the average recovery in past underground mining is likely to be slightly lower than 50 percent. However, the rounded figure of 50 percent is convenient and meaningful for use in discussion of past and near-future average recoverability in underground mining, and it is accepted for use in this report.

Obviously, many underground mines, particularly those that use the longwall mining method, achieve a much higher recovery than the selected average figure of 50 percent, and the gradual introduction of more efficient mining methods will probably result in a higher national average recovery in the future.

#### Strip Mining

Recoverability in strip mining may, under favorable conditions, be as much as 90 percent of the coal originally in the ground. Most strip-mine operators agree that the average recoverability in strip mining is on the order of 80 percent, and this figure is used in preparing many estimates of recoverable strip-mining resources.

#### Auger Mining

In auger mining the maximum possible recovery is about 75 percent, but, when many operations are considered, the actual average recovery is probably no more than about 50 percent—the same recovery assumed for other methods of underground mining. Actual recovery in auger mining is less than the possible maximum because the auger holes are generally smaller in diameter than the thickness of the bed being mined, and because spaces ranging in width from a few inches to 1 foot or more are routinely left between adjacent auger holes.

### DEPLETION OF RESOURCES

According to the foregoing, United States coal resources are being depleted at a rate of 2 times production for underground-mined coal, and 1.25 times production for strip-mined coal. In table 2 the estimates for 10 States are for remaining resources as of the date of the estimate, and these take into account losses associated with different types of mining for about 53 percent of cumulative past production. Other estimates are for original resources. To bring these estimates into approximate uniformity, they are reduced by production and assumed losses from the date of the estimate to January 1, 1974. For the sake of simplicity, this depletion rate is assumed to be 2 times production. This assumption introduces no significant error in estimates of remaining resources as of January 1, 1974, because (1) estimates of remaining resources take into account losses associated with 53 percent of past cumulative production; (2) strip-mined coal represents only 13 percent of past cumulative production; (3) production figures record only production from mines producing 1,000 tons or more per year and, thus, are slightly lower than actual production; and (4) estimates of resources are not as accurate as records of production and, in fact, are subject to change as new information is accumulated.

### COMPUTER METHODS OF ESTIMATING RESOURCES

For three States—Illinois, Oklahoma, and eastern Kentucky—the estimates discussed herein were prepared through use of computers. In

each of these studies, the individual punched card represented a block of coal of known average thickness, areal extent, and resource classification. The machine then performed the basic calculation—area × thickness × specific gravity—and printed out the total with other totals of the same resource classification. As the amount of data on coal increases, the use of computer techniques will certainly increase. But even this efficient electronic aid will not relieve the geologist of the strictly geologic problems of determining coal-bed correlations, interpretations of centers and trends of coal deposition, probable position of ancient shorelines, and locations of intraformational stream channels and other areas of post-depositional erosion that have reduced the tonnage of coal formerly present in many beds.

### STATISTICAL METHODS OF ESTIMATING RESOURCES

In recent years several engineers closely associated with the coal-mining industry have applied sophisticated statistical methods to the estimation of resources in areas of closely spaced exploratory drilling. (See Koch and Gomez, 1966; Pundari, 1966.) The chief virtue of these methods is to provide management with figures representing the maximum and minimum possible recovery in terms of tons and Btu content from the bed or beds being considered. The statistical methods work best when the geology of the coal and of the enclosing rocks is fully understood and much closely spaced development drilling information is available.

### RESERVE BASE

The reserve base is a selected portion of the identified resources deemed to be suitable for mining by 1974 methods. The coal in the reserve base is (1) in the measured and indicated (demonstrated) resource category; (2) in beds 28 or more inches thick for bituminous coal and anthracite, and 60 inches or more thick for subbituminous coal and lignite; and (3) in the 0- to 120-foot overburden category for lignite, which is deemed to be suitable only for strip mining, and in the 0- to 1,000-foot overburden category for the higher ranks of coal, which are deemed to be suitable for strip, auger, and underground mining methods. The reserve base may also include coal outside these parameters, if such coal is being mined locally or is considered to be commercially minable (U.S. Bureau of Mines, 1974b). The estimated reserve base of the United States by States and by method of mining is shown in table 5.

The figures in table 5 are for coal in the ground. At least 50 percent of the coal in the ground is recoverable, and this portion is termed "reserves," as distinguished from the reserve base. To avoid any possible ambiguity, "reserves" may also be termed "recoverable reserves."

TABLE 5.—*Coal reserve base of the United States, January 1, 1974, by State and by method of mining*

[Data from U.S. Bureau of Mines (1974b, p. 4). In millions ($10^6$) of short tons. Figures are for coal in the ground]

| State | Potential mining method | | Total |
|---|---|---|---|
| | Underground | Surface | |
| Alabama | 1,798 | 1,184 | 2,982 |
| Alaska | 4,246 | 7,399 | 11,645 |
| Arizona | (1) | 350 | 350 |
| Arkansas | 402 | 263 | 665 |
| Colorado | 14,000 | 870 | 14,870 |
| Georgia | 1 | .... | 1 |
| Illinois | 53,442 | 12,223 | 65,665 |
| Indiana | 8,949 | 1,674 | 10,623 |
| Iowa | 2,885 | (1) | 2,885 |
| Kansas | (1) | 1,388 | 1,388 |
| Kentucky, eastern | 9,467 | 3,450 | 12,917 |
| Kentucky, western | 8,720 | 3,904 | 12,624 |
| Maryland | 902 | 146 | 1,048 |
| Michigan | 118 | 1 | 119 |
| Missouri | 6,074 | 3,414 | 9,488 |
| Montana | 65,165 | 42,562 | 107,727 |
| New Mexico | 2,136 | 2,258 | 4,394 |
| North Carolina | 31 | (2) | 31 |
| North Dakota | .... | 16,003 | 16,003 |
| Ohio | 17,423 | 3,654 | 21,077 |
| Oklahoma | 860 | 434 | 1,294 |
| Oregon | 1 | (2) | 1 |
| Pennsylvania | 29,819 | 1,181 | 31,000 |
| South Dakota | .... | 428 | 428 |
| Tennessee | 667 | 320 | 987 |
| Texas | .... | 3,272 | 3,272 |
| Utah | 3,780 | 262 | 4,042 |
| Virginia | 2,971 | 679 | 3,650 |
| Washington | 1,446 | 508 | 1,954 |
| West Virginia | 34,378 | 5,212 | 39,590 |
| Wyoming | 27,554 | 23,674 | 51,228 |
| Total | 297,235 | 136,713 | 433,948 |

[1]Data insufficient to establish reserve base. [2]Less than 1 million tons.

## DISTRIBUTION OF IDENTIFIED RESOURCES IN SELECTED CATEGORIES

The distribution of total identified resources by region and by rank, as ascertained from data in tables 2, 3, and 5, is presented in table 6 and in figure 5*A* and discussed under separate headings that follow.

The identified resources in 21 States,[1] representing about 60 percent of the total identified resources, have been further classified according to

[1]Alabama, Arkansas, Colorado, Illinois, Indiana, Iowa, eastern Kentucky, Michigan, Missouri, Montana, New Mexico, North Carolina, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Texas, Virginia, Washington, and Wyoming.

thickness of overburden, reliability of estimates, and thickness of beds. The distribution of this large portion in the three additional categories is shown in figures *5B, 5C,* and *5D*. The distribution in these three categories, as of January 1, 1974, is skewed from the expected normal distribution by the tremendous amount of strippable coal in thick beds and in the measured category defined in recent years by an intensive exploratory effort. This tonnage is recorded very strikingly in table 5, which shows that strippable coal constitutes nearly one-third of the coal reserve base of the United States as of January 1, 1974. The effect of this large tonnage of strippable coal on the distribution patterns shown in figures *5B, 5C,* and *5D* is discussed under the appropriate headings.

## DISTRIBUTION ACCORDING TO REGION

The distribution of resources according to eight major coal basins or comparable large regions is given in table 6. These subdivisions provide a natural breakdown of data, and they can be considered separately or combined in various ways for study and analysis. Region 1, for example, represents coal readily available to the densely populated, highly industrialized Northeastern States. Regions 1 and 2 combined represent the Appalachian coal basin, which provides coal to the eastern seaboard, and coal that is exported to Japan, Canada, western Europe, and elsewhere. Regions 1, 2, 3, and 4 combined represent all coal east of the Mississippi River, whereas regions 5, 6, 7, and 8 combined represent all coal west of the Mississippi. Regions 1, 2, 3, 4, and 5 lie east of, and regions 6, 7, and 8 lie west of, an imaginary northeast-trending line extending from the panhandle of Texas to Minnesota, which marks an important division of regions and resources according to age and rank of coal. Regions 6 and 7 combined represent the Rocky Mountain and Northern Great Plains provinces. Region 8 represents the west coast and Alaska.

The tonnage figures in column 1 of table 6 are for the demonstrated reserve base as presented by States in table 5. The figures in column 2 express the same information in percent. The tonnage figures in column 4 are for total remaining identified resources as of January 1, 1974, as presented by rank and by States in tables 2 and 3. The figures in column 3 represent the difference between those in column 4 and column 1.

The amount of coal included in the demonstrated reserve base (table 6, col. 1) is much larger in some regions than in others because of differences in the thickness and number of coal beds and because of differences in the structure and topography of the major coal-bearing basins.

The large reserve base in region 1, the Northern Appalachian basin, as compared with the markedly smaller reserve base in region 2, the Southern Appalachian basin, results from the fact that the center of coal deposition was in the northern part of the Appalachian basin; hence, coal beds are thicker, more continuous, and more numerous in region 1. Also,

TABLE 6.—*Distribution, by basin or region, of the coal reserve base and of total remaining identified coal resources of the United States, January 1, 1974*

[In billions ($10^9$) of short tons. Leaders (...) indicate negligible amount of coal. Figures are for reserves and resources in the ground. At least half of the reserve base is recoverable]

| Basin or region | Overburden 0–3,000 feet | | | |
|---|---|---|---|---|
| | Demonstrated reserve base, 0–1,000 ft overburden[1] (from table 5) | | Resources in thin beds and inferred resources, 0–1,000 ft overburden; and identified resources in all beds 1,000–3,000 ft overburden | Total remaining identified resources (from table 3, rounded) |
| | Tons (1) | Percent (2) | (3) | (4) |
| 1. Northern Appalachian basin (Pa., Ohio, W. Va., and Md.) | 93 | 21 | 132 | 225 |
| 2. Southern Appalachian basin (eastern Ky., Va., Tenn., N.C., Ga., and Ala.) | 20 | 5 | 36 | 56 |
| 3. Michigan basin | ... | ... | .... | .... |
| 4. Illinois basin (Ill, Ind., and western Ky.) | 89 | 20 | 126 | 215 |
| 5. Western Interior basin (Iowa, Kansas, Mo., Okla., Ark., and Texas) | 19 | 4 | 63 | 82 |
| 6. Northern Rocky Mountains (N. Dak., S. Dak., Mont., Wyo., and Idaho) | 175 | 41 | 606 | 781 |
| 7. Southern Rocky Mountains (Colo., Utah, Ariz., and N. Mex.) | 24 | 6 | 211 | 235 |
| 8. West coast (Alaska, Wash., Oreg., and Calif.) | 14 | 3 | 123 | 137 |
| Total | 434 | 100 | 1,297 | 1,731 |

[1]Includes coal in the measured and indicated (demonstrated) category in beds 28 in. or more thick for bituminous coal and anthracite, and 5 ft or more thick for subbituminous coal and lignite. Maximum overburden is 1,000 ft for subbituminous coal, bituminous coal, and anthracite, and 120 ft for lignite. May include coal outside these parameters if such coal is being mined or is considered to be commercially minable (U.S. Bureau of Mines, 1974b).

the bulk of the coal-bearing sequence in the Northern Appalachian basin is preserved in a large syncline, whereas in the Southern Appalachian basin the entire upper part of the coal-bearing sequence was eroded in post-Pennsylvanian time.

The large reserve base in region 4, the Illinois basin, results from the fact that the Illinois basin is relatively shallow and the topography is relatively flat, so the coal is less than 1,000 feet below the surface over thousands of square miles. However, much of this coal can be reached only by vertical or inclined shafts.

The relatively small reserve base in region 5, the Western Interior basin, results from the fact that the coal-bearing rocks are thin; the coal beds are few in number and, in general, are thinner than beds in the Illinois basin.

The very large reserve base in region 6, the Northern Rocky Mountains, represents 41 percent of the total in column 1. This large tonnage and percentage reflects the fact that coal beds are very thick, numerous, and closely spaced; the coal-bearing rocks are nearly flat lying; and the topography is relatively flat over thousands of square miles in North Dakota, eastern Montana, and northeastern Wyoming. Much of the coal included in the reserve base of region 6 is within reach by strip-mining methods.

The modest reserve base in region 7, the Southern Rocky Mountains, as compared with that in region 6, reflects the fact that in most of region 7 the coal-bearing rocks are on the edges of moderately to steeply dipping structural basins. In parts of the region, particularly in the Wasatch Plateau and Book Cliffs of central Utah, the moderately dipping coal crops out at the bases of nearly vertical cliffs and, thus, passes below 1,000 feet of overburden a short distance from the outcrops. All the coal occurring in this topographic setting can be reached by drift mines, and even larger tonnages with overburden more than 1,000 feet thick can be reached conveniently through the same openings.

The small reserve base in region 8, the west coast, reflects the fact that in Washington most of the coal lies on the flanks of steeply dipping basins and, thus, passes below 1,000 feet of overburden a short distance from the outcrops, as well as reflecting the fact that in Alaska most of the coal is classified as inferred. The region actually contains larger total resources than is suggested by the small figure for the reserve base.

## DISTRIBUTION ACCORDING TO RANK

United States coal is very unequally distributed among four categories of rank. As shown numerically in table 2, and graphically in figure 5*A*, 43.1 percent of the original identified resources is bituminous coal, including 1.1 percent of low-volatile bituminous coal. By comparison, 28.1 percent is subbituminous coal, 27.7 percent is lignite, and only 1.1 percent is anthracite. It should be noted that the comparison shown in figure 5*A* is based on weight in tons. A comparison based on the contained heat value of the coal shows a marked percentage increase for bituminous coal, a modest percentage increase for anthracite, and progressive decreases for subbituminous coal and lignite, as indicated by the short tick marks to the right of the respective columns.

The geographic distribution of resources of the different ranks of coal is also very unequal. In the conterminous United States, about 83 percent of the identified resources of bituminous coal and anthracite lies east of an imaginary northeast-trending line extending from the panhandle of Texas to Minnesota (fig. 1), and about 99 percent of the subbituminous coal and lignite lies west of the line. This unequal geographic distribution is related in large part to differences in geologic age. Nearly all the coal in States east of the imaginary line is of Pennsylvanian age, whereas nearly all the coal in States west of the line is of much younger

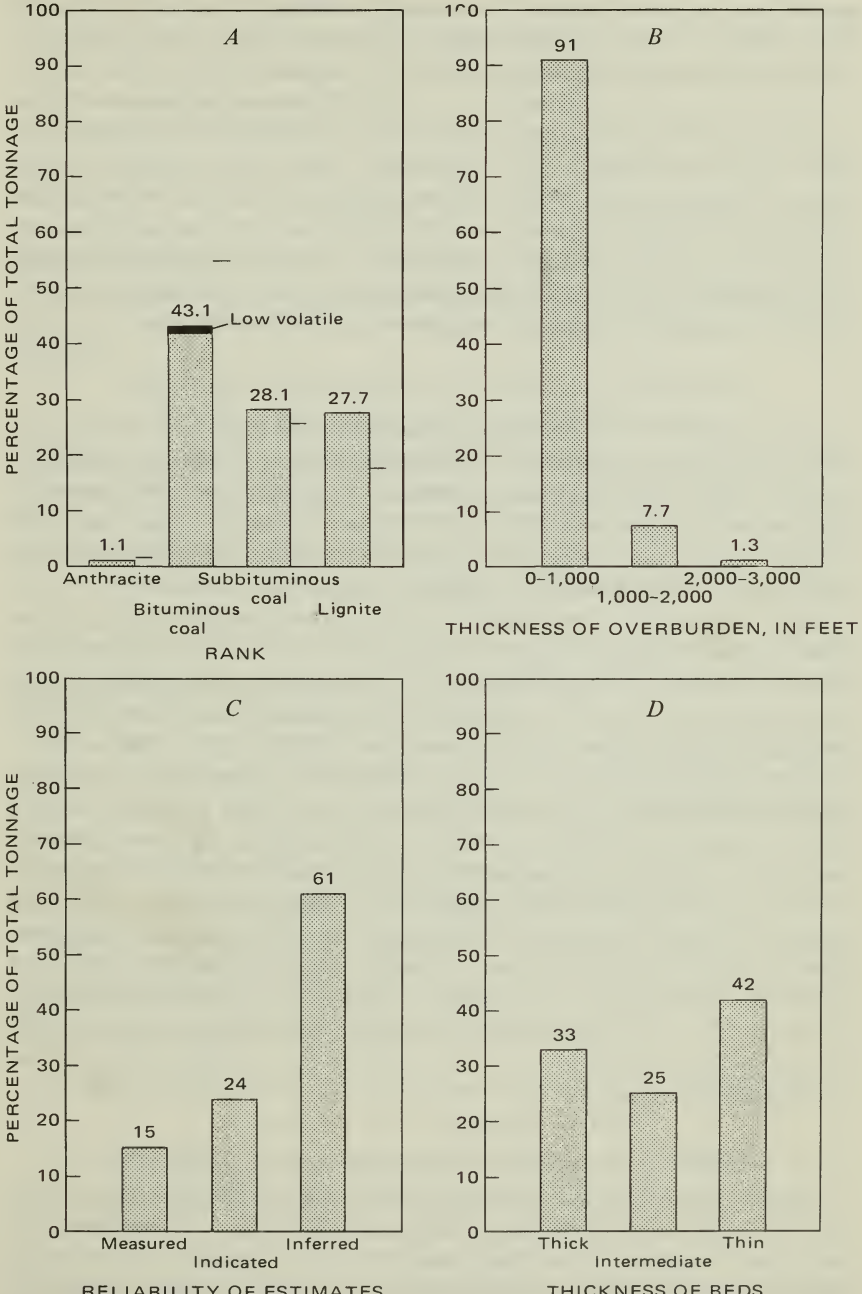



FIGURE 5.—Percentage distribution by weight of estimated original identified coal resources (*A*) in all States according to rank and in 21 States according to (*B*) thickness of overburden, (*C*) reliability of estimates, and (*D*) thickness of beds. Ticks beside or above bars in *A* indicate comparison by rank based on contained heat value of the coal.

age—Cretaceous or Tertiary. The younger, western coal attains high rank only where it has been deformed and altered by the forces that accompanied mountain building and by the intrusion of igneous rock.

The resources of subbituminous coal and lignite of the Western States are lower in heat value and are somewhat more difficult to ship and store than the more widely used bituminous coal of the Eastern States. However, the low-rank coals of the Western States are well suited for the production of electric power and the production of synthetic gas and liquid fuels, and in many parts of the West, they can be mined efficiently by stripping methods. With these advantages, the low-rank coals in the West have received increased attention since the late 1960's.

### DISTRIBUTION ACCORDING TO THICKNESS OF OVERBURDEN

Figure 5*B* shows the percentage distribution of classified resources in three categories according to thickness of overburden, in feet, as follows: 0–1,000, 1,000–2,000, and 2,000–3,000. It is noteworthy that 91 percent of the classified resources is less than 1,000 feet below the surface and that only 7.7 percent and 1.3 percent, respectively, are present in the 1,000- to 2,000-foot, and the 2,000- to 3,000-foot overburden categories.

The impressive concentration of the classified resources in the 0- to 1,000-foot overburden category is due to the fact that in most parts of the United States coal-bearing rocks lie near the surface, and exploration and mining are concentrated in this shallow-overburden zone. As a result, less attention has been given to coal more than 1,000 feet below the surface.

Only a small amount of coal is mined in the United States from beds 1,000–2,000 feet below the surface, and no appreciable amount is mined from beds more than 2,000 feet below the surface. Mining below 1,000 feet has been, or is being, carried on in the Pennsylvania Anthracite region; in the Coosa and Cahaba fields, Alabama; in the Book Cliffs, Utah; and locally in several fields in Washington. In Great Britain, Belgium, Germany, and Poland, however, mining has been extended to depths of 4,000 feet. As exploration and mine development are extended to greater depths in the United States, it is certain that the identified resources will be increased considerably by the addition of tonnage in the deeper overburden categories.

### DISTRIBUTION ACCORDING TO RELIABILITY OF ESTIMATES

Figure 5*C* shows the percentage distribution of classified resources in the 21 States in the measured, indicated, and inferred categories, as previously defined. Of the large tonnage thus classified, 15 percent is classed as measured, 24 percent as indicated, and 61 percent as inferred. The 15 percent classed as measured is somewhat large as compared with the 24 percent classed as indicated, primarily because intensive exploratory drilling for strippable coal in the early 1970's was restricted to

areas with no more than 200 feet of overburden. A restudy of the known strippable coal areas from the total resource point of view would undoubtedly result in an increase in the tonnage and percentage of coal that could be classed as indicated.

The figure of 61 percent for inferred resources is large because of lack of data in areas remote from outcrops. It does, however, express the approximate amount of coal that can be inferred to be present in areas remote from outcrops on the basis of current geologic information. Additional geologic mapping, exploratory drilling, and study in areas of inferred resources would undoubtedly increase the percentage of measured and indicated resources, and decrease the percentage of inferred resources.

### DISTRIBUTION ACCORDING TO THICKNESS OF BEDS

The terms "thick," "intermediate," and "thin," as used in figure 5*D*, refer to beds of coal in three thickness categories, which differ for the different ranks of coal. Defined as "thick" are beds of bituminous coal and anthracite more than 42 inches thick, and beds of subbituminous coal and lignite more than 10 feet thick. Defined as "intermediate" are beds of anthracite and bituminous coal 28–42 inches thick, and beds of subbituminous coal and lignite 5–10 feet thick. Defined as "thin" are beds of anthracite and bituminous coal 14–28 inches thick, and beds of subbituminous coal and lignite 2½–5 feet thick.

As recorded in the diagram, coal in thick beds makes up 33 percent of the total, coal in beds of intermediate thickness makes up 25 percent, and coal in thin beds makes up 42 percent. The relatively low percentage of resources in beds of intermediate thickness is due in part to the large amount of coal in thick beds that were delineated during the recent period of intensive exploration for strippable coal and in part to a human tendency to assign minimum thicknesses to beds in the inferred category and, thus, increase the percentage of coal in the thin category. The emphasis given to thick coal and to thin coal has, therefore, been at the expense of coal in the intermediate thickness category.

### DISTRIBUTION ACCORDING TO COMBINED CATEGORIES OF OVERBURDEN, RELIABILITY, AND THICKNESS OF BEDS

Figure 6 summarizes the distribution of resources in the three major categories presented in figures 5*B*, 5*C*, and 5*D*. Figure 6 clearly shows (1) the preponderance of resources in the 0- to 1,000-foot category, (2) the previously mentioned disproportionate relation between measured and indicated resources, and (3) the previously mentioned disproportionate relation between measured resources in thick beds as compared to indicated resources in thick beds. Resources are present in each of 27 possible categories in figure 6, except the one representing measured

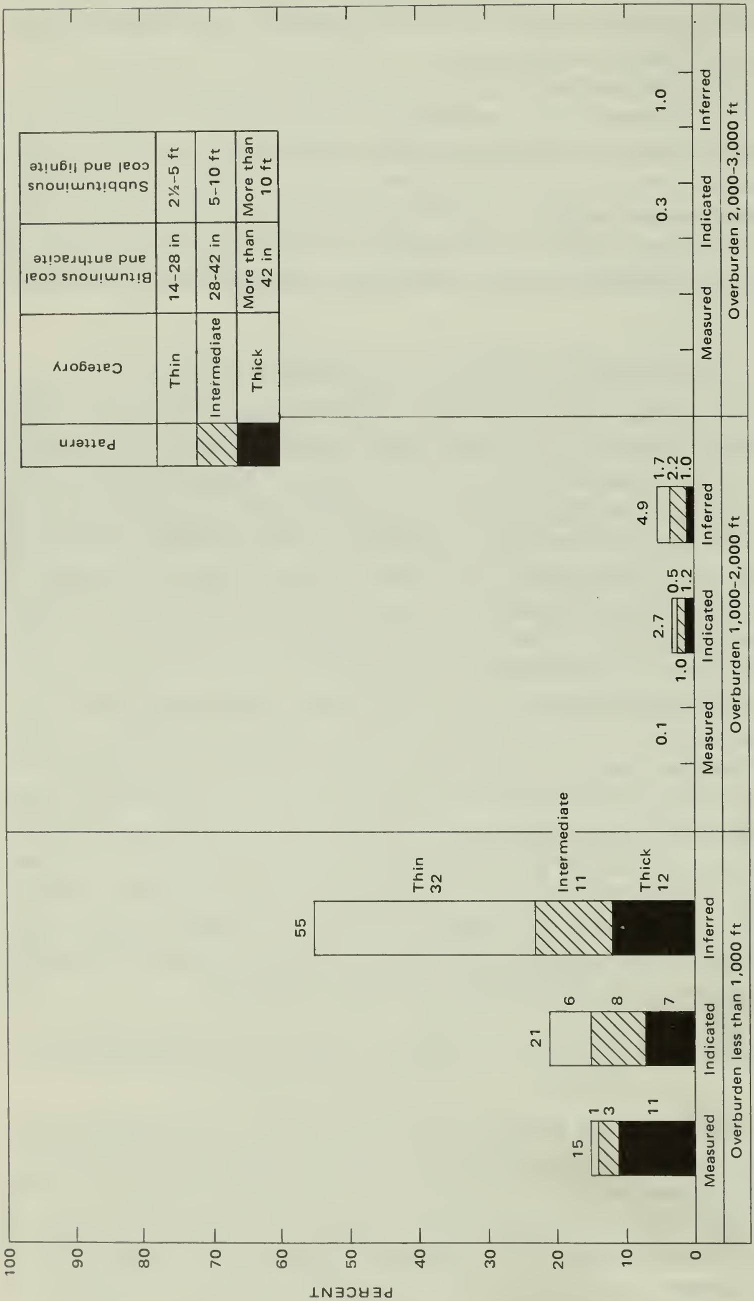



FIGURE 6.—Summary of percentage distribution by major resource categories of estimated original identified coal resources in 21 States.

resources in thin beds, 2,000–3,000 feet below the surface. The amounts in several categories are less than 1 percent of the total and could not be shown on a diagram at this scale.

As in figures 5*B*, 5*C*, and 5*D*, figure 6 shows the conservative character of the estimates of identified resources. The large percentages of resources in the indicated and inferred categories and the small percentages in the measured category are due to a lack of data, not to a lack of coal. The small percentage of coal in the 1,000- to 2,000-foot overburden category as compared with that in the 0- to 1,000-foot category is also due primarily to lack of data. The deeper overburden categories obviously contain additional coal that could not be included in estimates of identified resources. This additional tonnage is discussed later under a separate heading.

## ESTIMATES FOR STATES NOT COVERED BY CITED REPORTS

The estimates for Maryland and "Other States" used in table 2 are not taken from published State summary reports on coal resources but, instead, are based on a review and synthesis of data in detailed coal reports as explained below.

### MARYLAND

The coal-bearing rocks in Maryland cover an area of about 440 square miles in three parallel structural troughs that extend northeastward across Garrett and Allegany Counties in the western part of the State. The easternmost trough is divided by the Potomac and Savage Rivers into the Georges Creek basin to the north and the Upper Potomac basin to the south. The central trough is divided into the Castleman basin to the north and the Upper Youghiogheny basin to the south. The westernmost trough is known as the Lower Youghiogheny basin.

The remaining identified coal resources of Maryland as of January 1, 1950, are estimated to total approximately 1.2 billion tons. This estimate is based in part on two reports by Toenges and others (1949, 1952) on the Georges Creek basin, the northern half of the Upper Potomac basin, and the central part of the Castleman basin.

The remaining resources in the Georges Creek basin and the northern half of the Upper Potomac basin, as of January 1, 1947, were estimated to total 627 million tons (Toenges, Turnbull, and others, 1949). The estimate comprises resources in 10 beds, 18 inches or more thick, lying below the Pittsburgh bed. The Pittsburgh bed and the overlying Sewickley bed have been mined extensively and are now nearly depleted. The resources are classified according to the measured, indicated, and inferred categories, and according to four thickness categories. The coal is of low-volatile bituminous rank and is strongly coking.

The remaining resources in the central part of the Castleman basin, as of January 1, 1950, were estimated to total 232 million tons (Toenges, Williams, and others, 1952). The estimate comprises resources in six beds

14 inches or more thick. The resources are classified according to the measured, indicated, and inferred categories, and according to three thickness categories. The coal is of low- to medium-volatile bituminous rank and in general is strongly coking.

The estimates in the two reports were based on a substantial amount of data obtained from measurements in drill holes and at the outcrops, and are of a high order of accuracy. A minimum coal thickness of 18 inches was used in the report on the Georges Creek and Upper Potomac basins, whereas a minimum of 14 inches was used in the report on the Castleman basin and elsewhere.

In the areas covered by the two reports, the estimated remaining resources as of the period January 1, 1947, to January 1, 1950, total 859 million tons. The larger figure of 1.2 billion tons as the remaining resources of the State as of January 1, 1950, is derived from the 859-million-ton figure by a process of extrapolation, as summarized below.

The areas of the five coal basins in Maryland and the number and thickness of the contained coal beds suggest that the resources should be distributed about as follows: Georges Creek basin, 50 percent; Upper Potomac basin, 20 percent; Castleman basin, 15 percent; Upper Youghiogheny basin, 5 percent; and the Lower Youghiogheny basin, 10 percent.

The areas studied by Toenges and others (1949, 1952) in the Georges Creek, Upper Potomac, and Castleman basins make up about 84 percent of the total area of the three basins. If we assume that the estimate by Toenges and others represents 84 percent of the total resources of the three basins, and that the percentage distribution of resources in the five basins is correct, then the figure of 859 million tons represents about 70 percent of the total resources of the State (84 percent × 85 percent). On this basis, the remaining coal resources of Maryland as of January 1, 1950, are estimated to total about 1.2 billion tons.

Based as it is upon a broad extrapolation of data from several sources, this figure is subject to modification as more information becomes available about Maryland coal resources. It is, however, of the proper order of magnitude and is, therefore, useful for comparison with estimates of identified resources for other States.

## OTHER STATES

The coal resources of California, Idaho, Louisiana, Mississippi, Nebraska, Nevada, and Rhode Island are combined in table 2 under "Other States." In each of these States the resources are small, or the information about the occurrence and distribution of coal is so sparse that preparation of a meaningful estimate is impossible.

The accompanying table gives the estimated resources and the source of the estimate used for each State. The individual figures, however, have a

very low order of accuracy and are presented only to show how the totals by rank in table 2 were obtained.

*Estimated original coal resources of California, Idaho, Louisiana, Mississippi, Nebraska, Nevada, and Rhode Island*

[In millions ($10^6$) of short tons]

| State and field | Meta-anthracite | Bituminous coal | Subbituminous coal | Lignite | Total | Source of estimate |
|---|---|---|---|---|---|---|
| California | | | | | | |
| Amador County | .... | .... | .... | 50 | 50 | Total estimate of 100 million tons for California by Karp (1949). Also see Jennings (1957), Landis (1966). Provisional breakdown according to rank by present author. |
| Mount Diablo | .... | .... | 40 | .... | 40 | |
| Stone Canyon | .... | 10 | .... | .... | 10 | |
| Total | .... | 10 | 40 | 50 | 100 | |
| Idaho | .... | 600 | (1) | (1) | 600 | Campbell (1929); Kiilsgaard (1964). |
| Louisiana | .... | .... | .... | (1) | .... | Meagher and Aycock (1942). |
| Mississippi | .... | .... | .... | (2) | .... | C. S. Brown (1907). |
| Nebraska | .... | (2) | .... | .... | .... | Pepperberg (1910). |
| Nevada | .... | (2) | .... | (2) | .... | Hance (1913); Horton (1964); Toenges and others (1946); Mapel and Hail (1959). |
| Rhode Island | | | | | | |
| Narragansett basin | (3) | .... | .... | .... | .... | Ashley (1915); Toenges and others (1948). |
| Total, all States | .... | 610 | 40 | 50 | 700 | |

[1]Small.
[2]Insignificant.
[3]Small resources; believed to be too graphitic and too badly crushed and faulted to be economically recoverable as fuel.

## HYPOTHETICAL RESOURCES

The preceding analysis of data on the distribution of identified resources provides convincing evidence that unmapped and unexplored areas in known coal fields contain substantial additional resources that must be classed as hypothetical. The approximate magnitude of the additional hypothetical resources has been estimated by a process of extrapolation from nearby areas of identified resources, and estimates for each State are presented in separate columns in table 3. The evidence on which the estimates of hypothetical resources are based is summarized in the following paragraphs.

In most States for which modern estimates of identified coal resources have been prepared, substantial areas of coal-bearing rock were omitted from consideration because of lack of specific information about the occurrence and thickness of the coal. In Colorado, for example, 75 percent of the coal-bearing area was thus omitted; in eastern Kentucky, 13 percent was omitted; in Montana, 9.3 percent; in North Dakota, 1.7 percent; in Washington, 66 percent; and in Wyoming, 53.5 percent. A part of the estimated tonnage of hypothetical resources is present in such areas.

Because most exploration and mining in the United States is concentrated along outcrops, the amount of detailed information on coal decreases rapidly away from the outcrops, and is minimal at distances of only a few miles from the outcrops. Only general information is available about coal in the centers of the large coal basins. Therefore, most of the identified resources are confined to a narrow zone a few miles wide parallel to the outcrops of individual coal beds. This is well illustrated by the fact that 91 percent of the resources classified in figure 5*B* are less than 1,000 feet below the surface. A large part of the estimated hypothetical resources is assumed to be 1,000 feet or more below the surface.

Many coal-bearing areas, particularly those remote from present means of transportation or centers of use, have been mapped or examined only in reconnaissance. In such areas, points of information are widely spaced and confined to the thicker and better exposed beds. As a result, resource estimates tend to be small. The estimated hypothetical resources include an allowance for additional coal that should be discovered when detailed geologic mapping is extended into such areas.

In areas covered by reconnaissance mapping, and in many others as well, data on the coal-bearing rocks and on individual coal beds are generally insufficient to permit the establishment of correlations between coal beds in all parts of the areas. Where correlations cannot be established, the estimated resources are restricted to the vicinity of known outcrops. Where correlations can be established, resources can be inferred to exist at greater distances between outcrops, and the total estimated resources tend to be larger. The estimated hypothetical resources include an allowance for coal that may be delineated as a result of improved knowledge of stratigraphy and of coal bed correlations.

From the foregoing discussion and from the distribution pattern of identified resources shown in figure 6, it is apparent that the bulk of the estimated hypothetical resources is in the 1,000- to 2,000-foot overburden zone and that smaller amounts are present in other overburden zones. The probable distribution, according to thickness of overburden, of the total estimated coal resources of the United States in the identified and hypothetical categories combined is shown in figure 7.

The estimated hypothetical resources are, of course, only an approximation, based primarily on extrapolation from the more reliable and more useful estimates of identified resources. Although large, the estimated hypothetical resources are, for the most part, relatively inaccessible for mining at present, and a more exact delineation of the magnitude, distribution, and utility of such resources can be ascertained only by future detailed geologic mapping, exploration, and study. Nevertheless, the estimated hypothetical resources constitute an important part of the total resource that needs to be considered in future planning for the utilization of all energy resources.

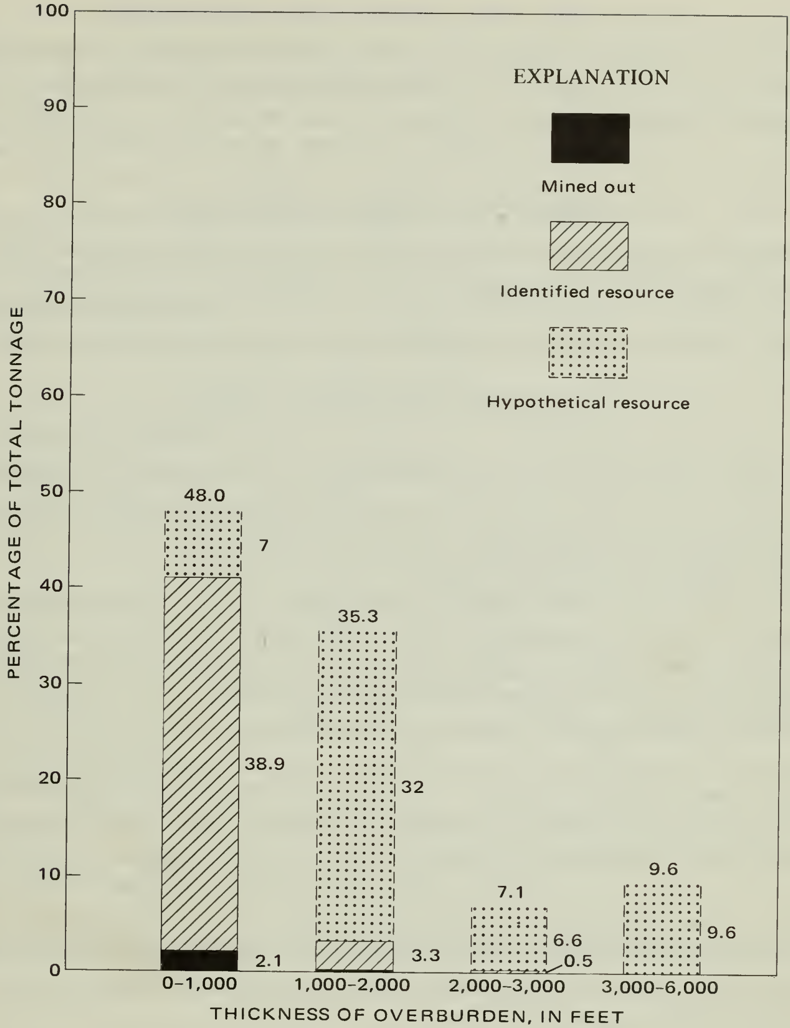



FIGURE 7.—Probable percentage distribution of total United States coal resources according to thickness of overburden.

## SPECULATIVE RESOURCES

The resources presented in tables 2 and 3 and discussed under the headings of identified and hypothetical resources represent total resources in known coal fields within limits established by the minimum thickness of coal beds and the maximum thickness of overburden. Coal that can be assigned to the speculative category is discussed briefly under the next two headings.

## COAL MORE THAN 6,000 FEET BELOW THE SURFACE

Coal-bearing rocks more than 6,000 feet below the surface are known to occur in the deeper parts of the Uinta basin of Utah and Piceance Creek basin of Colorado, and in the Green River, Wind River, and Bighorn basins of Wyoming. Information on this deeply buried coal is not routinely collected, because at depths of 6,000 feet and more the rock pressure and temperature are very high, and underground mining to such depths is, in the present economy, possible only for gold and similar high-value commodities. Nevertheless, deeply buried coal may at some distant date become a target for underground gasification as thinking turns toward other sources of deep-seated energy, such as geothermal energy.

## COAL ON THE CONTINENTAL SHELVES

The continental shelves are made up in part of thick sedimentary deposits, laid down in a near-shore environment that was conducive locally to the formation of coal deposits. The lignite deposits of Texas and Louisiana, for example, were formed in Tertiary time in a near-shore environment at the former edge of the Gulf of Mexico.

At many places in the world, coal beds that crop out on land extend for unknown distances under the sea in rocks of the innermost continental shelves. In Nova Scotia, Chile, Japan, and Great Britain, mining of such beds has progressed under the sea for several miles. In Japan, undersea mining is facilitated by an air shaft sunk to the coal bed from an island several miles offshore. In Great Britain, where the coal deposits on land have been seriously depleted through centuries of mining, drilling exploration for additional supplies of coal has been extended seaward under the Firth of Forth. In western Turkey coal crops out on the edges of the Black Sea, the Aegean Sea, and the Sea of Marmara and locally dips below these bodies of water; in the Zonguldak field, mining extends below the level of the Black Sea. Coal is also known to extend seaward under the continental shelves off the Sydney field, Australia, the northern Alaska field, and the island of Borneo.

All these known deposits may be reached by adits starting on shore and extending seaward. The amount of coal on the inner continental shelves that can be extracted economically from such deposits at the present time is probably no more than a few hundred million tons for the entire world. No such deposits are present in the United States.

No coal deposits are known on the outer continental shelves. However, by analogy with coal deposits on land and on the inner continental shelves, the geologic conditions on the outer continental shelves are favorable for the occurrence of coal. Obviously, the presence or absence of such coal can be determined only by exploratory drilling.

Past studies of coal and associated rocks in the coal fields of the United States have yielded a clear understanding of the vertical sequence and

lateral variations of beds that form on the edges of advancing and retreating seas, and this information can be applied to study of rocks in the continental shelves. In such studies even a thin coaly layer of no possible commercial value is a meaningful stratigraphic and physiographic marker of great interpretative value.

## NEED FOR ADDITIONAL WORK

This summary study of United States coal resources has revealed obvious deficiencies in knowledge of the distribution, extent, and correlation of coal beds:

1. Substantial areas had to be omitted from consideration in preparing estimates of identified resources (p. 43).
2. A very large percentage of the identified resources is classified as inferred (p. 38–39; fig. 5*C*).
3. Very little information is available on coal in overburden zones deeper than 1,000 feet (p. 38; fig. 5*B*).
4. In many areas, particularly the eastern coal fields, where information is generally considered to be more abundant, much of the geologic mapping was done in the period 1900–20 and does not provide the data necessary for modern needs.

Full knowledge about coal in the United States is thus dependent on a continuing, active program of detailed geologic mapping and exploratory drilling in the coal-field areas, accompanied by periodic inventories of resources.

The cooperation between Government and industry in the accumulation, preservation, and analysis of coal-resource data, which has been so effective in the preparation of recent resource estimates, should be strengthened and improved at every opportunity.

## PREVIOUS ESTIMATES OF UNITED STATES COAL RESOURCES

Previous estimates of United States coal resources fall into three categories according to the points of view and the specialized needs of the estimators.

1. Estimates prepared by M. R. Campbell and associates in the period 1909–29, and adopted with minor revisions by later writers, were for total resources in the ground. The present estimate will be compared with estimates in this group.
2. An estimate prepared by a committee of the United States Coal Commission of 1922 was for potentially recoverable resources.
3. An estimate prepared by the United States Army Corps of Engineers was for recoverable reserves in areas suitable for locations of synthetic liquid-fuel plants.

These estimates differ considerably in magnitude because of the different assumptions and procedures on which they were based. However,

when the points of difference are taken into account, the older estimates are found to be in reasonably good accord with each other and with the improved and more detailed estimate presented in this report. Pertinent information about each of the older estimates and the present estimate is summarized in the following paragraphs.

### M. R. CAMPBELL, 1909–29

The first considered estimate of the total original coal resources of the United States was prepared by M. R. Campbell of the U.S. Geological Survey and published with successive minor revisions several times between 1909 and 1929. (See Campbell and Parker, 1909; Campbell, 1913, 1917 [revised and reprinted 1922; reprinted 1929], and 1929.) These pioneer estimates served as the principal source of information on United States coal resources for more than 40 years.

The Campbell estimates represented total resources originally present in the ground before the advent of mining. With the limited data then available, Campbell, of necessity, made statistical allowance for coal in all parts of all coal-field areas, and, primarily for this reason, the estimates could not be classified according to resource categories used in the preparation of modern estimates.

In the Campbell estimates the following minimum bed thicknesses were used for the three major ranks of coal:

| *Rank* | *Minimum bed thickness (in.)* |
|---|---|
| Bituminous coal and anthracite | 14 |
| Subbituminous coal | 24 |
| Lignite | 36 |

An average specific gravity of 1.3, which is equivalent to a weight of 1,770 tons per acre-foot, was used for coal of all ranks. Except for the major breakdown of resources according to rank, no other resource categories were employed.

The estimate prepared by Campbell and Parker (1909) included data by States in the 0- to 3,000-foot overburden category only. Estimates prepared by Campbell in the period 1913–22 (Campbell, 1913, 1917, 1922) included data by major coal basins or regions only and included coal in both the 0- to 3,000-foot and the 3,000- to 6,000-foot overburden categories. A later estimate prepared by Campbell (1929), and estimates by Hendricks (1939), and Buch, Hendricks, and Toenges (1947) included data by States only and did not include coal in the 3,000- to 6,000-foot overburden category. The accompanying table shows all estimates for the conterminous United States prepared by Campbell and adopted or adjusted by subsequent writers.

*Total original coal resources of the conterminous United States as estimated by M. R. Campbell and subsequent writers*

[In billions ($10^9$) of short tons]

| Source of estimate | Original resources in the ground | | |
|---|---|---|---|
| | Overburden 0–3,000 ft | Overburden 3,000–6,000 ft | Total |
| Campbell and Parker (1909) | 3,076 | [1]667 | 3,743 |
| Campbell (1913, 1917) | 3,554 | 667 | 4,221 |
| Campbell (1922, see Campbell, 1917) | 3,553 | 667 | 4,220 |
| Campbell (1929); Hendricks (1939) | 3,215 | [1]667 | 3,882 |
| Buch, Hendricks, and Toenges (1947) | 3,144 | [1]667 | 3,811 |
| This report, adjusted | [2]3,405 | [3]383 | 3,788 |

[1]No estimate in this category in cited report. Campbell estimate of 667 billion tons for Rocky Mountain States presented in reports of 1913–22 inserted to facilitate comparison.

[2]Remaining identified and hypothetical resources of 3,580 billion tons as of Jan. 1, 1974, from table 3, minus 260 billion tons for Alaska, which was not included in previous estimates; plus 85 billion tons, representing past production and estimated losses from beginning to mining to Jan. 1, 1974.

[3]Original resources of 388 billion tons from table 3, minus 5 billion tons for Alaska, which was not included in previous estimates.

## COMPARISON BETWEEN THE CAMPBELL ESTIMATE AND THE PRESENT ESTIMATE

The accompanying table includes for purposes of comparison the new estimate presented in tables 2 and 3 and in earlier pages of this report. To facilitate comparison, the new estimate had to be adjusted downward by a small amount, and the older estimates had to be adjusted upward by small amounts, as explained in the table footnotes. With these adjustments to a common basis, the table shows only minimal differences in the two overburden categories and in the totals between the present estimate and the older estimates. Internally, however, the new estimate is significantly different from the older estimates, as discussion in following paragraphs will show.

### DIFFERENCE IN ESTIMATES IN THE 0- TO 3,000-FOOT OVERBURDEN CATAGORY

In the 0- to 3,000-foot overburden category, 47 percent of the tonnage reported in the present estimate is in the identified category and 53 percent is in the hypothetical category, which provides a very significant initial breakdown of the data that was not considered in preparing the older estimates. Of the tonnage reported in the identified category, 91 percent is 0–1,000 feet below the surface and is divided into additional resource categories according to thickness of beds and relative reliability of the estimates. (See fig. 6.) The division of the tonnage in the identified category into these many additional categories, some of which have economic significance and all of which have long-term resource significance, provides detail and flexibility to the present estimate that was beyond the scope of the older estimates.

When estimates for individual States are compared, the range in size of State estimates in the present report is markedly larger than the range in

the several Campbell reports. For example, in the present report estimates for 7 States are larger than those of the older Campbell reports; estimates for 8 States are in fairly close accord; and estimates for 14 States are smaller. Of some interest is the fact that the more recent estimates for the 9 Appalachian basin States are all smaller than the older Campbell estimates.

With these marked points of difference, the fact that the present total for resources in the 0- to 3,000-foot overburden category is so nearly the same as older Campbell totals is apparently merely a coincidence.

### DIFFERENCE IN ESTIMATES IN THE 3,000- TO 6,000-FOOT OVERBURDEN CATEGORY

For coal in the 3,000- to 6,000-foot overburden category the new estimate is somewhat smaller than the Campbell estimates primarily because of improved knowledge concerning the structure of the deeper coal basins in the Rocky Mountain region. Campbell and his associates assumed that these basins were shallower than they actually are and, thus, could contain substantial resources in both the 0- to 3,000-foot and the 3,000- to 6,000-foot overburden categories. Subsequent oil and gas exploration in the Rocky Mountains provided the evidence that most of these coal basins are very deep. In the Uinta basin of Utah and Colorado, for example, the coal-bearing rocks dip steeply basinward and are more than 6,000 feet below the surface only a few miles from the outcrops. In the Green River basin of southwest Wyoming, the coal-bearing rocks are locally as much as 15,000 feet below the surface; and in the Wind River and Bighorn basins of central and northern Wyoming the coal-bearing rocks are as much as 20,000 feet below the surface. The steep dips on the margins of such basins require an appreciable reduction in the estimated resources in the 3,000- to 6,000-foot overburden category—from 667 billion tons in the Rocky Mountain States as estimated by Campbell (1917 [1922 repr.]) to 388 billion tons for all States, as shown in table 3. Although Campbell considered deeply buried coal only in the Rocky Mountain region, the new estimates presented in table 3 of this report show modest additional amounts of such coal in Alabama, Alaska, Oklahoma, Pennsylvania, Virginia, and Washington, which were not included in the Campbell estimates.

### SUMMATION AND APPRAISAL OF THE CAMPBELL ESTIMATE

The points of difference between the two estimates and the reasons therefor, as summarized above, permit several broad generalizations:

1. The Campbell estimate was an adequate extrapolation of the data available in the period 1909–29.
2. In the present new estimate, the figures for individual States range more widely than they did in the older Campbell estimates. Thus, in the present estimate, figures for 7 States are larger

than those in the Campbell estimates; figures for 8 States are nearly the same; and the remainder are smaller.

3. The reliability and completeness of the coal resources estimate for an individual State is controlled primarily by the reliability of regional coal-bed correlations. The chances of improving, and probably increasing, estimates are best in those States having many poorly correlated coal beds and substantial resources. The chances for improvement are least in those States having few well-correlated coal beds and small resources.
4. As additional information is accumulated about coal in the United States, and as new State estimates are prepared in the future, the spread between State estimates is more likely to increase than to decrease.
5. The new State estimates are much more useful than the older Campbell estimates because nearly half of the total included in the estimates is based on a bed-by-bed analysis of coal in the immediately accessible parts of the coal-field areas, and the results of this analysis have been published in considerable detail in the many State summary coal reports cited in table 2.

## UNITED STATES COAL COMMISSION COMMITTEE REPORT, 1922

The recoverable coal resources of the United States as of January 1, 1922, were estimated to be 1,634 billion tons by a committee established by the United States Coal Commission. This committee, known at that time as the Engineers' Advisory Valuation Committee, was requested to estimate the market value of the Nation's coal mines and of total recoverable coal. The Coal Commission did not accept the estimate of the valuation committee for use in the Commission reports, but permission was given for separate publication by the committee (Am. Inst. Mining Metall. Engineers, 1924).

The committee's estimate of recoverable resources, now only of historic value, was based on estimates of original resources in individual States prepared by Campbell and by several State surveys. These estimates were reduced to allow for estimated future mining losses and to exclude "thin and unavailable coal." No specific information is contained in the committee report as to the criteria used in reducing the Campbell figures for original resources. It is interesting to note, however, that the estimate of the valuation committee is about 46 percent of the Campbell figure of the same period expressed as remaining resources in the ground in the 0- to 3,000-foot overburden category. In the past, a few writers have unintentionally implied that the estimate of the valuation committee differed significantly from the Campbell estimate because these writers failed to recognize that the committee's estimate was for recoverable resources, whereas the Campbell estimate was for coal resources in the ground.

### UNITED STATES ARMY CORPS OF ENGINEERS, 1952

A study of data available on United States coal resources to determine general areas suitable for the location of synthetic liquid-fuel plants was completed in 1952 by Ford, Bacon, and Davis under the auspices of the U.S. Army Corps of Engineers (1952, p. 17, 18). The estimated recoverable coal reserves as of January 1, 1949, delineated during the course of that study, totaled about 170 billion tons, of which a maximum of 126 billion tons was deemed suitable for immediate large-scale use in the manufacture of synthetic liquid fuels.

The major objective of the Corps of Engineers survey was to outline large blocks of coal that would be immediately available for large-scale mining to supply hypothetical synthetic liquid-fuel plants. The maximum depth of coal considered in the Corps of Engineers estimate was 1,500 feet, and the minimum thickness of coal considered was 24 inches for bituminous coal and 48 inches for lignite. With these parameters, the Corps of Engineers figure of 170 billion tons for recoverable reserves is very conservative, but it is appropriate in terms of the study objectives. If, for the moment, this figure is doubled to 340 billion tons to represent coal in the ground, it is found to be smaller than, but roughly comparable to, the figure of 424 billion tons for the reserve base of the United States, which is discussed on page 00 and presented in detail in table 5.

## COKING-COAL RESOURCES

Coke is usually manufactured from blends of two or more coals of different rank and composition and may incorporate small amounts of other ingredients, such as anthracite fines, petroleum coke, or low-temperature char. The term "coking coal" therefore refers typically to a variety of coals and only rarely to a single coal with unique properties. Although a single coal of medium-volatile bituminous rank that is low in ash, sulfur, and phosphorus will produce a satisfactory metallurgical coke, resources of such coal are small, and the properties desired in a coke are more readily obtained and standardized by the blending procedure. The blending procedure also permits use of coals that individually do not yield a satisfactory coke. Most coking-coal blends contain 15–30 percent low-volatile bituminous coal, which is strongly coking, and 85–70 percent high-volatile bituminous coal, which is weakly coking. In 1972 low-volatile bituminous coal constituted 17.6 percent of the total coal made into coke, medium-volatile constituted 16.5 percent, and high-volatile constituted 65.9 percent (U.S. Bureau of Mines Minerals Yearbook, 1972, p. 451). In addition to rank, the nature of the original plant constituents of coal is a factor in determining coking properties, as are the deleterious constituents—ash, sulfur, and phosphorus. With the many variables that must be taken into account, modern coking-coal blends have become complex mixtures of carbonaceous material.

Most of the areas of high-rank and high-quality coal best suited for the manufacture of coke and coke chemicals are in the northern part of the Appalachian basin, principally in West Virginia, Pennsylvania, eastern Kentucky, and Virginia. Substantial amounts of coal suitable for the manufacture of coke are also present in Alabama at the southern end of the Appalachian basin. Bibliographies accompanying summary reports on individual Appalachian basin States, as cited in table 2, contain information on the occurrence and composition of coking coal in the respective States. Additional information is contained in reports by Dowd and others (1950–52c, 1955–56), Wallace and others (1952–55b), Williams and others (1954–56), Hershey and others (1955–56b), Blaylock and others (1955–56), Travis and others (1956), Lowe and others (1956), Provost and others (1956), and Tavenner and others (1956).

Coal in the Illinois basin is weakly coking, but because of its proximity to the steel manufacturing center at the southern end of Lake Michigan small amounts of it are used in this area in coking-coal blends that incorporate higher rank coal from the Appalachian basin. (See Jackman and Helfinstine, 1967.)

In a few areas in the West, principally in Colorado, Utah, Oklahoma, Arkansas, Washington, and New Mexico, coal is produced that is satisfactory for the manufacture of coke when used in blends. The most important areas are the Raton Mesa region, Colorado–New Mexico; the Sunnyside field, Utah; and the Somerset–Crested Butte–Carbondale region, Colorado. These areas stand out prominently in plans for the industrial development of the West. Summary information about resources of coking coal in the West is contained in reports by Averitt (1966), Haley (1960), R. B. Johnson (1961), Landis (1959), and Trumbull (1957).

Because of the almost limitless possibilities of blending coals and hydrocarbons in the manufacture of coke, and because of the certainty that the acceptable amounts of impurities in coke will be allowed to increase and coking properties to decrease as the higher rank and higher grade bituminous coals are depleted, it is likely that lower rank and lower quality bituminous coal will be beneficiated for use in the future. If so, the resources of such coal are very large. Of the remaining identified bituminous coal resources as of January 1, 1974 (table 2), about 35 percent, or about 260 billion tons, is high enough in rank, quality, and composition to be used if required in major or minor proportions in coking-coal blends.

## LOW-VOLATILE BITUMINOUS COAL

Low-volatile bituminous coal is high in heat value, low in volatile matter, and generally low in ash and sulfur contents. Of all coal used in the manufacture of coke, low-volatile bituminous coal is the most important because (1) it is very strongly coking and can be used in coking-

coal blends to upgrade much larger resources of high-volatile bituminous coal, which is less strongly coking; (2) most areas of low-volatile bituminous coal are on the east edge of the Appalachian coal basin near centers of population and industry on the eastern seaboard; and (3) it contributes less to air pollution than lower ranks of coal.

Low-volatile bituminous coal is mined extensively for the manufacture of domestic coke, and it constitutes a substantial part of coal and coke exported to Japan, Canada, and Western Europe. It is also mined extensively for use by the manufacturing industries and the electric utilities because the same properties that render it important in the manufacture of coke also render it desirable to these industries.

This choice fuel is in relatively short supply. An analysis of data on the occurrence of low-volatile bituminous coal in State summary reports on Pennsylvania, West Virginia, Maryland, Virginia, Alabama, Oklahoma, Arkansas, and Colorado suggests that the original resources of low-volatile bituminous coal in the ground totaled about 20,000 million tons. This figure is about 1.1 percent of the total original identified coal resources of the United States. This proportion will not change significantly, because any change in the figure for resources of low-volatile bituminous coal is likely to be accompanied by a comparable change in the figure for total resources.

In many areas of less desirable and less readily accessible coal in the United States, the remaining resources are very nearly equal to the original resources because little mining has been done. The areas containing low-volatile bituminous coal, on the other hand, are being mined out very rapidly, and the remaining resources of this coal are now less than 1 percent of the remaining identified resources of the United States. With only a limited supply of low-volatile bituminous coal available, it is apparent that use of low-volatile coal for purposes other than the manufacture of coke is a waste of a national asset and that coking operations and metallurgical processes must ultimately be adjusted to permit increased use of lower rank coal.

## STRIPPABLE COAL RESOURCES

The amount of coal mined and potentially minable by strip-mining methods has increased steadily throughout the years, concomitant with an impressive increase in the number, size, and efficiency of strip-mining machines. In 1917 strip mining accounted for only 1 percent of the total United States production of bituminous coal, subbituminous coal, and lignite as compared with 46.6 percent in 1973. By the end of 1973 strip mining had accounted for 13 percent of total cumulative United States coal production. During 1973 almost the entire production of 10 States—Alaska, Indiana, Kansas, Missouri, Montana, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming—was obtained by strip-mining methods.

In 1917 the largest steam shovel in operation had a capacity of only a few cubic yards. By 1957 the largest shovel in operation had a capacity of 70 cubic yards, or 105 tons. In succeeding years, still larger shovels were constructed, and in 1972 the largest shovel in operation had a capacity of 180 cubic yards, or 265 tons, and was capable of removing 16,000 tons of overburden an hour. Shovels of 200-cubic-yards capacity are a future possibility.

In 1968 a walking dragline with a 250-foot boom and a 145-cubic-yard bucket of 215-ton capacity was placed in operation in Indiana. This dragline can handle overburden to a maximum depth of 96 feet (Coal Age, 1968b). In 1969 a walking dragline with a 310-foot boom and a 220-cubic-yard bucket of 325-ton capacity was placed in operation in southern Ohio. This dragline can handle overburden to a maximum depth of 185 feet (Coal Age, 1969). Several draglines with 360-foot booms are on order.

The increase in size and efficiency of strip-mining machinery has permitted a steady increase in the average and in the maximum thickness of overburden removed, and as a result the ratio of average overburden thickness to average recovered coal thickness has also increased. This trend is shown in the accompanying table.

*Average and maximum thickness, in feet, of overburden removed and average thickness of bituminous coal and lignite recovered by strip mining in the United States for selected years*

[Modified from Young (1967, p. 18)]

| | 1946 | 1950 | 1955 | 1960 | 1965 | 1970 (est.)[1] |
|---|---|---|---|---|---|---|
| Average thickness of overburden removed | 32 | 39 | 42 | 46 | 50 | 55 |
| Maximum thickness of overburden removed | .... | .... | 70+ | 100 | 125 | 185 |
| Average thickness of coal recovered | 5.2 | 5.1 | 4.9 | 5.1 | 5.2 | 5.0 |
| Ratio of average overburden thickness to average coal thickness | 6:1 | 8:1 | 8.5:1 | 9:1 | 10:1 | 11:1 |

[1]Est., estimated.

The averages presented in the table include several noteworthy extremes. In the famous Wyodak mine, Wyoming, for example, a 90-foot bed of coal is recovered by removing 25–40 feet of overburden. In Alaska, the average thickness of overburden removed in 1965 was nearly 67 feet, and the average thickness of coal recovered was nearly 43 feet; these figures yield a very favorable statewide ratio of 1.4:1.

In marked contrast, the average thickness of overburden removed in Oklahoma in 1965 was 43 feet, and the average thickness of coal recovered was 1.5 feet; these figures yield a statewide ratio of 29:1 (Young, 1967, p. 18). In one outstanding operation in Alabama, overburden ranging in thickness from a few feet to nearly 100 feet, and averaging about 60 feet, is removed to recover a bed of high-quality metallurgical coal 22 inches thick (Coal Age, 1968a). These figures yield a ratio of 22:1. In at least one operation in Kansas, 45 feet of overburden was removed to recover 1.5 feet

of high-quality coal; these figures yield a ratio of 30:1. In Illinois, ratios larger than 30:1 have been handled and are being planned in parts of large-scale stripping projects where the coal is 28–36 inches thick.

These examples suggest that within the lift and swing limits of existing machinery the 30:1 ratio is technically feasible as a maximum for present and near-future strip mining. However, in the present highly competitive energy market, the success of each strip-mining operation depends on many factors in addition to the ratio between thickness of overburden and thickness of coal. These factors include thickness and quality of the coal; density and hardness of the overburden; capacity of machinery; size of property; selling price of coal from competing sources; distance to transportation facilities and markets; availability of electric power, labor, and supporting facilities; and many environmental considerations. Because of the continued availability of coal with more favorable overburden ratios, the average nationwide ratio will continue to be much less than 30:1 for many years, as may readily be seen by an examination of the average ratios for recent years shown in the table.

The remaining strippable coal reserve base of the United States as of January 1, 1974, totals 137 billion tons as shown by States in column 2 of table 5. Based on an earlier study by the U.S. Bureau of Mines (1971), about 80 percent of this total, or 110 billion tons, is within reach by present machinery and methods of mining, but only 50 percent of this amount, or 55 billion tons, is economically recoverable.

The figure of 55 billion tons is too large to be appreciated except by comparison with smaller, more comprehensible numbers. It is, for example, nearly 10 times the cumulative strip-coal production in the United States from the beginning of strip mining to January 1, 1974, and it is 200 times the production of strip coal in 1974. These comparisons are not intended to suggest, and obviously do not represent, life expectancy of the economically recoverable strippable coal reserves because the rate of production and the estimated size of the strippable coal reserve base are certain to change in the future.

About 70 percent of the economically recoverable strippable coal reserves contains 1 percent or less sulfur, which is a major factor contributing to present interest and increased production of such coal.

## RECLAMATION OF STRIP-MINED LANDS

The abandoned spoil banks of past strip mining in the United States are usually cited as a major objection to future strip mining. It should be noted, however, that the older abandoned spoil banks are a product of their time—when the amount of disturbed land was relatively small; when coal mining was a highly competitive, low-profit business; when the value of the land before mining was low; and when there was no strong public pressure for reclamation.

The practices of the past obviously do not need to be the practices of the future, as evidenced by the fact that highly advanced levels of land reclamation have been achieved in England, Germany, and parts of the United States. Actually, reclamation of strip-mined land is easier and less costly than almost any other environmental objective. Such reclamation can be accomplished in large part by the same men and machinery that remove the coal, and no new or expensive technology is required. When reclamation is carried on concurrently with strip mining, the cost of returning the land to a pleasing contour with a surface that will support vegetation should be in the range of $2,000 to $6,000 per acre (R. E. Matson, Montana Bureau of Mines and Geology, oral commun., April 1975). The fact that these figures may be higher than the original value of the land is not serious, because the annual return on the restored land surface, however small, will ultimately exceed the cost of reclamation.

When the costs of reclamation are expressed in terms of the coal recovered, they are found to be surprisingly low. Table 7 shows the costs required for various thicknesses of coal recovered at four levels of estimated reclamation costs per acre. The costs are much lower in the West than in the East because western coals are thicker than eastern coals, and the acreage disturbed by strip mining in the West is small in relation to the amount of coal recovered. The western coals and associated rock are also low in sulfur, and the disturbed overburden in the West is much less acidic than the disturbed overburden in the East.

The estimated reclamation costs shown in the table range from less than 1 cent per ton of coal recovered to $1.44 per ton. It is likely that the national average will be in the lower part of this range at roughly 25¢ per ton of coal recovered.

TABLE 7.—*Costs of reclaiming strip-mined land as related to thickness of underlying coal*

[Costs of reclamation are expressed in dollars and cents per ton of coal recovered by strip mining at four assumed levels of cost per acre for reclamation of the strip-mined land]

| Thickness of coal[1] (feet) | Estimated recovery per acre[2] (tons) | Assumed costs of reclamation per acre | | | |
|---|---|---|---|---|---|
| | | $1,000 | $2,000 | $3,000 | $4,000 |
| 2 | 2,800 | $0.36 | $0.72 | $1.08 | $1.44 |
| 3 | 4,300 | .23 | .46 | .69 | .92 |
| 4 | 5,700 | .18 | .35 | .53 | .70 |
| 5 | 7,100 | .14 | .28 | .42 | .56 |
| 10 | 14,200 | .07 | .14 | .21 | .28 |
| 15 | 21,300 | .05 | .095 | .14 | .19 |
| 20 | 28,400 | .035 | .07 | .105 | .14 |
| 25 | 35,400 | .028 | .056 | .084 | .112 |
| 50 | 70,800 | .014 | .028 | .042 | .056 |
| 100 | 141,600 | .007 | .014 | .021 | .028 |

[1]Thin beds, 2 to 5 ft, typical of strip mining in the Eastern and Central United States; thick beds, 10 to 100 ft, typical of Northern Rocky Mountain and Great Plains regions.

[2]Assuming specific gravity of coal to be 1.3 and recovery to be 80 percent.

## PEAT RESOURCES

Peat is the first stage in the alteration of plants to coal. It is a water-saturated accumulation of plant debris formed on poorly drained land in regions of cool climate or high humidity where evaporation is slow and plants may flourish. In this environment, oxidation and decomposition are retarded, and the plant debris accumulates year after year and is slowly compressed with minimum loss of organic matter or of carbon. At this early stage of accumulation and alteration, the structure of individual plant components is generally visible without the aid of a microscope.

Peat is an important fuel in Europe, but only small quantities have been produced commercially as fuel in the United States because of the abundance of other fuels. However, the United States contains substantial deposits of peat, and it is produced commercially for a variety of nonfuel purposes. Air-dried peat is a source of concentrated organic matter, and it contains about 2 percent nitrogen. Because of these properties, it is used in the United States primarily as a soil conditioner. In 1972, for example, 85 percent of the peat consumed in the United States was used directly as an admixture to soil, and the remainder was used primarily in potting mixtures and fertilizers, and for packing flowers, shrubs, and bulbs. Small amounts were used in the culture of mushrooms and earthworms.

During 1972 United States production of peat totaled 577,000 tons, and imports, primarily from Canada, totaled 310,000 tons (U.S. Bureau of Mines Minerals Yearbook 1972, p. 898).

The peat resources of the conterminous United States were described in considerable detail by Soper and Osbon (1922), who estimated that the original peat resources totaled 13,827 million tons, calculated on an air-dried basis. Of this total only about 11 million tons was mined between 1922 and January 1, 1973.

The peat resources occur primarily in local deposits distributed throughout two general regions. The northern peat region, which contains about 80 percent of the total resources, comprises Minnesota, Wisconsin, Michigan, eastern South Dakota, the northern parts of Iowa, Illinois, Indiana, Ohio, and Pennsylvania, and New York, New Jersey, and the New England States. The Atlantic coastal region, which contains approximately 19 percent of the total resources, comprises the southern part of Delaware, the eastern parts of Maryland, Virginia, North Carolina, South Carolina, and Georgia, and all of Florida. Small deposits of peat also occur in a narrow belt of land adjoining the gulf coast; in the valleys of the Sacramento and San Joaquin Rivers and in Siskiyou, Los Angeles, Orange, and San Bernardino Counties, Calif.; and in the basins of lakes and rivers in Oregon, Washington, and the Rocky Mountain States.

Table 8, taken from Soper and Osbon (1922), shows the original resources of peat in the United States, calculated on an air-dried basis, by

TABLE 8.—*Estimated original resources of peat in the conterminous United States, calculated on an air-dried basis, by regions and States*

[From Soper and Osbon (1922, p. 92-93. In millions of short tons]

| Region and State | Resources |
|---|---|
| Northern region: | |
| Minnesota | 6,835 |
| Wisconsin | 2,500 |
| Michigan | 1,000 |
| Iowa | 22 |
| Illinois | 10 |
| Indiana | 13 |
| Ohio | 50 |
| Pennsylvania | 1 |
| New York | 480 |
| New Jersey | 15 |
| Maine | 100 |
| New Hampshire | 1 |
| Vermont | 8 |
| Massachusetts | 12 |
| Connecticut | 2 |
| Rhode Island | 1 |
| Total | 11,050 |
| Atlantic coastal region: | |
| Virginia and North Carolina | 700 |
| Florida | 2,000 |
| Other States[1] | 2 |
| Total | 2,702 |
| Other regions: | |
| Gulf coast[2] | 2 |
| California | 72 |
| Oregon and Washington | 1 |
| Total | 75 |
| Total, all regions | 13,827 |

[1]Includes Delaware, Georgia, Maryland, and South Carolina.
[2]Exclusive of Florida.

regions and States. The report by Soper and Osbon includes tables of resources classified by counties for the States having important peat resources, as well as detailed descriptions of individual peat deposits.

More recent and more detailed studies of the occurrence and origin of peat in the Eastern United States have been published by Cameron (1968, 1970a, b, c).

## NONBANDED COALS

Nonbanded coals occur locally as thin layers in many coal beds. When such coal is present in thickness and extent sufficient to attract attention, it is generally referred to as cannel coal or as boghead coal according to the brief definitions below. Nonbanded coals are dense, compact, and uniform in texture and they generally break with a conchoidal fracture. They are formed of finely comminuted plant fragments of uniform size but of heterogeneous composition. The particles of material in nonbanded coals must have been transported by wind and deposited in the open water of ponds and lakes in the original peat-forming swamps. Information on the distribution of nonbanded coal in the United States has been summarized by Ashley (1918).

### CANNEL COAL

Cannel coal is a nonbanded coal that under a microscope exhibits conspicuous spore coats in the groundmass of comminuted plant material. Although very conspicuous, the spore coats rarely account for as much as 10 percent of the total bulk of nonbanded material.

### BOGHEAD COAL

Boghead coal is a nonbanded coal characterized by an abundance of cutinous or waxy envelopes of a colonial type of algae. The algal residue

may constitute as much as 90 percent of the bulk of a boghead coal, but more commonly the algal residue is dispersed in a groundmass of finely comminuted, heterogeneous plant material in much the same way that spore coats are dispersed in cannel coal. The term "torbanite" is applied to a dominantly boghead coal mined in Scotland and South Africa.

#### INTERMEDIATE VARIETIES

The distinction between cannel coal and boghead coal cannot be made with the unaided eye. Even under a microscope the distinction is not always obvious because intermediate varieties of cannel-boghead or boghead-cannel coal are more common than the two named and defined end members.

#### USES

The nonbanded coals, particularly the boghead coals, tend to be high in hydrogen and high in volatile hydrocarbons and, thus, are rich in oil-forming components. Boghead coal in Scotland has long been distilled for oil. The largest deposit of nonbanded coal in the United States is in the Santo Tomas field of Webb County, Tex. (Ashley, 1919; Lonsdale and Day, 1937). The coal from this field has yielded on low-temperature distillations as much as 52 gallons of oil and 5,600 cubic feet of gas per ton (Ashley, 1919, p. 260–261). The oil is composed largely of unsaturated hydrocarbons but might be amenable to upgrading by modern cracking and hydrogenation processes.

The nonbanded coals tend to ignite easily and to burn with a smoky yellow flame. They are mined on a small scale and sold locally, generally under the more commonly used term "cannel coal," for use in open household grates.

## PRODUCTION OF COAL IN THE UNITED STATES[2]

The mining and distribution of coal is the second largest mineral industry in the United States, surpassed only by the much larger petroleum and natural gas industry. The 598 million tons of bituminous coal and anthracite mined in 1973 was valued at about $5.1 billion as a prepared product at the mine tipples. This is more than the value of any other metallic or nonmetallic mineral commodity and is more than the value of all metallic minerals combined.

The cumulative production of coal in the United States to January 1, 1974, totals 42.3 billion tons, which is equivalent to about 11 cubic miles of broken coal. Half of this huge total has been mined since January 1, 1934. Figure 8 shows the percentage distribution, by States, of this cumulative production. The diagram shows the preponderance of

[2]All statistical statements in this chapter are based on data in U.S. Bureau of Mines Minerals Yearbooks for 1973 and prior years.

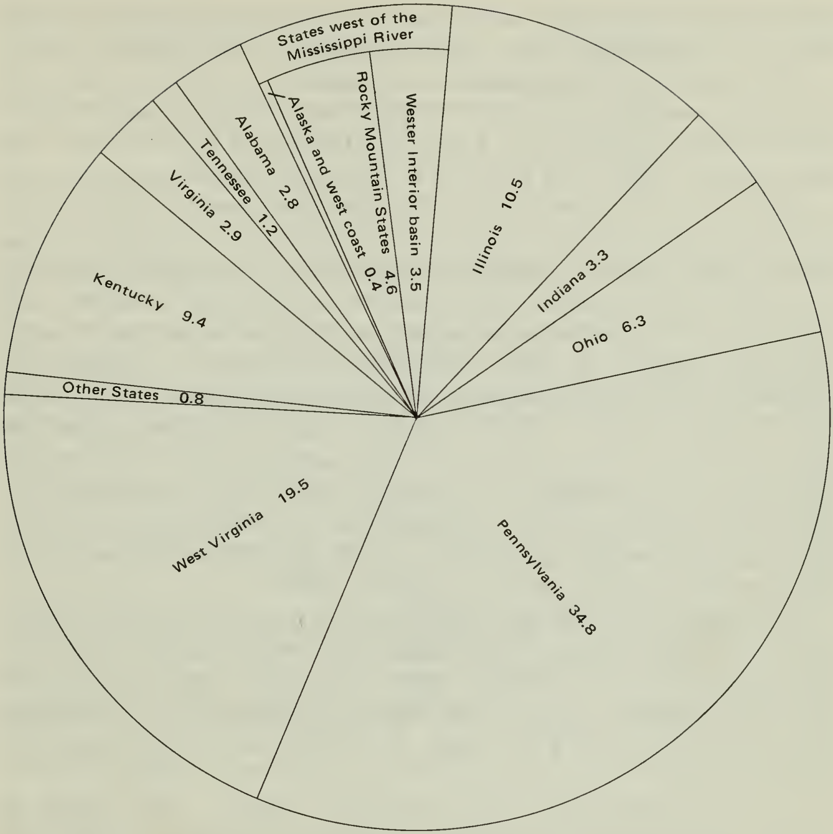



FIGURE 8.—Percentage distribution, by States, of cumulative coal production in the United States to January 1, 1974.

production from Pennsylvania and West Virginia and the fact that more than 90 percent of past production has come from coal fields east of the Mississippi River.

Before the Revolutionary War, coal was mined only in a very small way by the American colonists and was used mostly in blacksmith forges. Wood was the major fuel. With increased industrialization and growth in population that characterized the 1800's, coal production increased very rapidly and more than doubled in some decades in the first half of the 19th century. Production continued to double every 10 years or so until the end of World War I. An early peak in coal production was reached in 1918 when 678 million tons was mined. Between the early 1800's and the end of World War I, coal was a major household, commercial, and industrial fuel. After World War I, coal production began a long, irregular decline, due in part to the great expansion in use of petroleum and natural gas,

which began in the 1920's and in part to the business depression of the 1930's. An unprecedented low of 359 million tons was recorded in 1932.

Following the 1932 depression, coal production increased slowly and irregularly until the outbreak of World War II, which brought about a rapid increase in production. A second, all time peak of 688 million tons was reached in 1947. After World War II, coal production again declined as railroads turned almost exclusively to diesel-powered locomotives, and as oil and natural gas became the preferred fuels for household heating and for other purposes formerly served by coal. This decline continued until 1961, when a new low of 420 million tons was mined. Since 1961 coal production has increased substantially in response to the lower cost of coal made possible by the continued improvement in strip-mining machinery (p. 55) and in response to increased demands by the electric utility industry (p. 77). The 612 million tons of bituminous coal and anthracite produced in 1970 was the highest annual figure reported since 1947; this amount would fill a continuous line of coal cars extending 2½ times around the circumference of the Earth. (A line of loaded coal cars 1 mile long is assumed to hold 10,000 tons.) In 1971–73 annual production was a few million tons below the high of 1970.

In 1972 there were 4,879 operating bituminous coal and lignite mines in the United States, ranging from small mines that produced as little as 1,000 tons per year to very large, highly mechanized mines that produced more than 5 million tons per year. About 57 percent of 1972 production was obtained from 280 large mines of 500,000 tons annual capacity or larger.

Of the total bituminous coal and lignite mined in 1972, about 48 percent was shipped by rail, 27 percent by water, 11 percent by truck, and the remaining 14 percent was used at the mine or was unclassified in detail as to the method of shipment. Rail shipments of coal represented 21 percent of the total freight handled by the railroads and yielded $1.4 billion, or about 10.5 percent of total gross railroad freight revenue.

Use of unit trains for transporting coal over long distances has increased at a rapid rate since the late 1960's, and this trend should result in a future increase in the amount and percentage of coal moved by rail.

Two coal slurry pipelines have been constructed and operated at different places and times in the United States, and this method of transport may be used on a more substantial scale in the future.

Most of the coal mined in the United States is obtained from beds ranging in thickness from 3 to 6 feet, as shown in the table on page 63, taken from a report by Young (1967, p. 2).

The substantial 12.5 percent credited to beds generally less than 3 feet thick is obtained primarily by strip- and auger-mining methods. Improvements in strip- and auger-mining machinery over the years have resulted in a modest but steady increase in the percentage of coal obtained from the thinner beds.

| Thickness of beds mined (ft) | *Percent of 1965 production* |
|---|---|
| <3 | 12.5 |
| 3–6 | 61.5 |
| 6–8 | 19.4 |
| >8 | 6.6 |
| Total | 100.0 |

Coal-mining methods have changed greatly through the years. In 1920, for example, less than 1 percent of underground production of bituminous coal and lignite was mechanically loaded, whereas by 1973 a record 99.2 percent was mechanically loaded. In 1920 strip mining accounted for only 1.5 percent of the coal produced, whereas in 1970 strip mining accounted for a record 46.9 percent. In 1973 strip mining accounted for 46.6 percent.

The pronounced trend toward mechanization in coal mining has resulted in an increase in productivity per man, and a comparable decrease in the number of men employed. In 1920, when total coal production was somewhat higher than at present, the average productivity was about 4.5 tons per man per day, whereas by 1969 the average productivity was about 19.9 tons per man per day. Over the same period the average number of men employed daily declined from 639,547 in 1920 to 124,532 in 1969. Since 1969 productivity has declined slightly because of increased emphasis on miners' health and safety, and the average number of men employed daily has increased commensurately.

## CONCENTRATION OF RESOURCES AND PRODUCTION IN SELECTED BEDS

Of the many coal beds known in the United States, a few are thick and continuous over large areas, or they possess special properties that make them commercially desirable. These beds contain a substantial part of the total resources, and they have yielded the bulk of past production. Beds in this select category are discussed briefly below. Most are in the eastern half of the United States because the older, Paleozoic coal beds in the East are more continuous than the younger, Cretaceous and Tertiary coal beds of the West; also, the beds in the East have been explored, mined, and studied in greater detail.

### MAMMOTH COAL ZONE

The Mammoth coal zone contains more coal and has yielded more coal than any other coal zone or coal bed in the Pennsylvania Anthracite region (Arndt and others, 1968, p. 131). At a minimum, the zone consists of a single thick coal bed, which attains an average thickness of 10 feet in the Northern Anthracite field and 29 feet in the Southern Anthracite field, and locally is as much as 65 feet thick. At the maximum, the zone consists of a sequence about 150 feet thick that contains as many as six coal beds or splits, and five intervening zones of barren rock. At most places the

Mammoth zone contains two or three splits, which are known as the Top and Bottom, or Top, Middle, and Bottom, splits. The individual splits range in thickness from 4 to 14 feet, and where 2 or more splits are present, the aggregate thickness generally exceeds the thickness of coal in nearby places where a single, thick, unsplit bed is present.

The Mammoth zone is persistent and easily recognized. It originally extended over an area of at least 3,300 square miles but is now preserved in the 484-square-mile area of the four structural basins that comprise the Pennsylvania Anthracite region.

### PITTSBURGH BED

The Pittsburgh bed has been described by Ashley (1938, p. 56) as the most valuable individual mineral deposit in the United States and perhaps in the world. It is of minable thickness and is remarkably uniform in character over an area of about 6,000 square miles in the northern part of the Appalachian basin, in Pennsylvania, West Virginia, Maryland, and Ohio. It is recognizable as a stratigraphic unit over a much larger area. According to Cross (1952, p. 34) and Wanless (1956, p. 122), it attains maximum thickness in western Maryland and northeastern West Virginia and thins in all directions from that area. It is 22 feet thick at places in Mineral County, W. Va., and almost 20 feet thick in small areas in Preston County, W. Va. Farther west, in southwestern Pennsylvania and northern West Virginia, it is 8–14 feet thick. In easternmost Ohio and southern West Virginia it is 4–6 feet thick. It thins to generally less than 3 feet in northwestern Pennsylvania, eastern Ohio, and northern Kentucky. Much of the thicker, more accessible coal has, of course, been mined out, but large areas of coal of minable thickness remain in the ground.

An extrapolation of data assembled by Ashley (1938) and by Latimer (1962) indicates that by January 1, 1974, the bed had yielded about 9 billion tons of coal. This is about 35 percent of the total cumulative production of the Appalachian basin and 21 percent of the total cumulative production of the United States to the same date.

Coal from the Pittsburgh bed has a high heat content and excellent coking properties. It was a major factor in the many decisions that led to the establishment of the iron and steel empire at Pittsburgh, Pa. (See Eavenson, 1938; Davis and Griffen, 1944.)

### LOWER KITTANNING (NO. 5 BLOCK) BED

The Lower Kittanning bed is thinner than the Pittsburgh bed, but it covers a larger area and contains larger resources. The Lower Kittanning bed extends almost continuously throughout the northern part of the Appalachian basin in Pennsylvania, West Virginia, Maryland, and Ohio. It also extends into northern Kentucky, where it is known as the Princess (No. 6) bed.

According to Wanless (1956, p. 112) and Headlee and Nolting (1940, p. 44–49), the Lower Kittanning is thickest in central West Virginia and thins very gradually in all directions. With minor local variations, thicknesses are commonly as follows: Central West Virginia, maximum of 12 feet; northern West Virginia, 4 feet; western Pennsylvania, 2½–4 feet; Ohio, 2–4 feet; Maryland, generally less than 3 feet; and southern West Virginia, 3–7 feet.

The Lower Kittanning bed has been mined in most of the areas where it is more than 4 feet thick, and it is second only to the Pittsburgh bed as a major source of coal in the Appalachian basin.

### UPPER FREEPORT BED

The Upper Freeport bed is less uniform in thickness than the overlying Pittsburgh bed or the underlying Lower Kittanning bed because it was subjected to local uplift and erosion before deposition of the overlying rocks. Nevertheless, it is a persistent bed throughout large areas in Pennsylvania, West Virginia, and Ohio, and is the third most important bed in the northern part of the Appalachian basin, both in production and in contained resources.

Data assembled by Wanless (1956, p. 120), Headlee and Nolting (1940, p. 33–37), and Ashley (1928, p. 112) show that the bed is thickest on the east edge of the basin in southwestern Pennsylvania and central West Virginia.

In Pennsylvania the Upper Freeport bed is thick and continuous in the counties around Pittsburgh and in the southwestern part of the State, where it ranges in thickness from 2 to 10 feet and is 4–6 feet thick over considerable areas.

In West Virginia the Upper Freeport bed is considered to be of minable thickness and purity over an area of 1,165 square miles in a belt running north-south through the central part of the State. In the northern part of the belt it ranges in thickness from 3 to 12 feet and is 4–5 feet thick over large areas. It thins to the south and is generally less than 2 feet thick in Clay and Braxton Counties.

In Ohio the Upper Freeport bed is very irregular in thickness. It is locally as much as 8 feet thick but typically thins within a few miles (or tens of miles) to less than 14 inches. Nevertheless, its wide distribution makes it the fourth most important bed in Ohio in known resources.

### CAMPBELL CREEK (NO. 2 GAS) BED

The Campbell Creek (No. 2 gas) bed of West Virginia and its correlatives, or approximate correlatives—the Lower Elkhorn bed of easternmost Kentucky and the Imboden bed of southwestern Virginia—extend over an area of about 3,500 square miles in the three States. The bed generally ranges in thickness from 2 to 8 feet and locally is

as much as 10 or 13 feet. Estimated original resources total about 9.5 billion tons. The bed is relatively low in ash and sulfur and high in heat value, and it has been mined extensively in the three States and used primarily for the manufacture of coke. (See Headlee and Nolting, 1940, p. 88–92; Huddle and others, 1963, p. 90; and Andrew Brown and others, 1952, p. 28.)

### UPPER ELKHORN NO. 3 BED

The Upper Elkhorn No. 3 bed is of minable thickness over an area of 2,000 square miles in eastern Kentucky, and 1,470 square miles in West Virginia, where it is known as the Cedar Grove bed. It has been mined extensively in southeastern Kentucky and in Logan, Mingo, Boone, and Kanawa Counties, W. Va. Where mined, it is typically 3–4 feet thick, but local maximum thicknesses of 8 feet have been observed. It has yielded more coal than any other bed in eastern Kentucky, and it contains the largest remaining resources (Huddle and others, 1963, p. 173).

### FIRE CLAY BED

At most exposures the Fire Clay coal bed contains in its lower part an easily recognizable parting of hard, medium-brown, flint clay, typically 4–6 inches thick. Because of this distinctive parting, the Fire Clay bed is an important unit in stratigraphic correlations and structural interpretations throughout eastern Kentucky, southern West Virginia, Virginia, and Tennessee (Wanless, 1956, p. 104). The bed is of minable thickness over an area of 1,800 square miles in eastern Kentucky and over an area of 1,170 square miles in West Virginia, where it is known as the Chilton bed. It has been mined extensively in southeastern Kentucky and in Logan and Mingo Counties, W. Va. Where actively mined, it is typically 3–4 feet thick, but locally it is as much as 8 feet thick. In eastern Kentucky, the Fire Clay bed is second only to the Upper Elkhorn No. 3 bed in past production and in remaining resources (Huddle and others, 1963, p. 173).

### POCAHONTAS BEDS

The name "Pocahontas" has been assigned to nine coal beds that crop out in the basal part of the Pennsylvanian sequence on the east edge of the Applachian bituminous coal basin near the town of Pocahontas, Va. These beds extend over a relatively small area in Tazewell and Buchanan Counties, Va., and adjoining counties in West Virginia. The Pocahontas beds collectively contain relatively small resources as compared with other more extensive beds in the two States, but they are mined very intensively because of their low ash, high heat content, and special coking properties. The coal in the Pocahontas area is of medium- to low-volatile bituminous rank and is very strongly coking. For this reason it can be used

to upgrade blends incorporating larger amounts of high-volatile bituminous coal, which is less strongly coking. It is shipped for this purpose to major steel-manufacturing centers throughout the Eastern United States.

The Pocahontas beds are numbered from 1 to 9 beginning at the bottom of the sequence. The Pocahontas No. 3 bed is the most important of the group. As described by Headlee and Nolting (1940, p. 143–145) and by Andrew Brown and others (1952, p. 11), it extends as a minable bed over 650 square miles in West Virginia, and a somewhat smaller area in Tazewell and Buchanan Counties, Va. Within this area the coal ranges in thickness from 2 to 11 feet and is about 8 feet thick in most operating mines. The coal thins to the southwest and to the northeast and is not mined in those areas. The Pocahontas No. 3 bed has been mined intensively since 1883, and most of the thicker, more accessible coal has been mined out. Most of present mining in the area is in other Pocahontas beds, which are of similar quality but of smaller areal extent.

### SEWELL BED

The Sewell coal bed, including several well-known correlatives or approximate correlatives, extends the full length of the Appalachian basin from Pennsylvania to Alabama and is also represented in the southern part of the Illinois basin (Wanless, 1956, p. 104, fig. 6). However, it is best developed and mined most extensively in West Virginia. As described by Headlee and Nolting (1940, p. 122–126), the Sewell bed attains minable thickness over an area of about 2,000 square miles in central West Virginia. In this area, the Sewell bed generally ranges in thickness from 2 to 6 feet but locally attains a maximum thickness of about 10 feet. Where the bed is thicker, it generally contains one or more partings or a layer of impure coal at the base. The estimated original resources in the Sewell bed in West Virginia total about 8 billion tons, which establishes it as the fourth most important coal bed in the State.

The Sewell bed is thin and relatively unimportant in eastern Kentucky, but it thickens in Tennessee, where it is known as the Sewanee bed, and again in Alabama, where it is known as the Mary Lee coal zone. It is, therefore, discussed also under these local names.

### SEWANEE BED

The Sewanee coal bed contains larger resources and is mined more extensively than any other bed in Tennessee. It crops out throughout the central and southern parts of the Tennessee coal field and extends into nearby parts of Georgia. In the southernmost counties of Tennessee, where the bed is actively mined, it is typically 2½–3½ feet thick, but locally it is as much as 4 feet thick (Luther, 1959, p. 183–184, 189–190, 197–199, 260–262).

### MARY LEE COAL ZONE

The Mary Lee coal zone covers a larger area and contains more coal than any other bed in Alabama. As described by Culbertson (1964, p. 29–31), the zone consists of five closely spaced beds that vary considerably in thickness, persistence, and spacing. At places an individual bed is thick enough to be mined separately. At other places two or more beds coalesce into one bed 10 feet thick or more, including partings. The Mary Lee zone contains at least one bed over an area of 1,500 square miles. Mines located on a bed in this zone typically recover 4–6 feet of coal and locally may recover as much as 10 feet. Coal from the Mary Lee zone is relatively high in ash and low in sulfur. It has been mined extensively in the eastern part of the Warrior basin for the manufacture of coke.

### PRATT BED

The Pratt bed, about 400 feet above the Mary Lee coal zone, was an important factor in the establishment of the iron and steel industry at Birmingham, Ala. Through the years it has yielded large amounts of excellent coking coal to support this industry, and it still contains large resources. The bed is of minable thickness over an area of 775 square miles in the Warrior coal basin. Near Birmingham, Jefferson County, Ala., it ranges in thickness from 30 to 75 inches and averages about 45 inches. Farther west, in Walker County, it thins to less than 36 inches and is lower in rank and somewhat higher in ash and sulfur (Culbertson, 1964, p. 32).

### NO. 5 BED

The No. 5 bed is the most widespread and commercially valuable coal bed in the Eastern Interior coal basin. It is known in Illinois as the No. 5, Harrisburg, or Springfield bed; in Indiana as the No. V, Petersburg, Alum Cave, or Springfield bed; and in western Kentucky as the No. 9 bed (Weller and Wanless, 1939, p. 1379, 1390). It is of minable thickness over an area of about 20,000 square miles in the three States, and it is recognizable as a lithologic unit over an area of about 30,000 square miles. In southeastern Illinois it is 4–5 feet thick over large areas; in Indiana it has an average thickness of 5 feet and locally is as much as 11 feet thick; and in western Kentucky it is uniformly 4 feet 8 inches to 4 feet 10 inches thick throughout its area of occurrence. From the standpoint of resources and production, this coal bed is the most important bed in Indiana and western Kentucky, and it is second only to the Herrin No. 6 bed in Illinois. It is more widespread and continuous than the Pittsburgh bed and other important beds in the Appalachian basin.

### HERRIN (NO. 6) BED

The Herrin (No. 6) bed is recognizable over an area of about 15,000 square miles in the Eastern Interior coal basin, where it is second in

commercial importance only to the No. 5 bed. It is known in western Kentucky as the No. 11 bed, and in Indiana as the VIb bed (Weller and Wanless, 1939, p. 1379, 1391). This coal attains maximum thickness in southern Illinois, where it is locally as much as 14 feet thick. In central Illinois and in western Kentucky, the Herrin (No. 6) bed is 5–7 feet thick over large areas. It thins eastward and is relatively unimportant in Indiana. It also thins toward the northwest edge of the basin. From the standpoint of resources and production it is the most important coal in Illinois, but it is followed closely by the No. 5 bed. In western Kentucky, the Herrin No. 6 bed (No. 11 bed of Kentucky) is second in commercial importance only to the No. 5 bed (No. 9 bed of Kentucky).

The Herrin (No. 6) bed is thin but persistent over considerable areas in the Western Interior coal basin. It is correlated with the Mystic bed of Iowa (Landis, 1965, p. 26) and with the Lexington bed of Missouri (Weller and others, 1942, p. 1591).

### WEIR-PITTSBURG BED

The Weir-Pittsburg, or Cherokee, bed crops out as a mappable unit or a recognizable horizon from southern Wagoner County, Okla., across southeastern Kansas into north-central Missouri—a straight-line distance of about 380 miles. In Oklahoma it is also known as the Pawpaw bed, and in Kansas it is also known as the lower Weir-Pittsburg bed. The bed is thickest and best developed near the type locality in southeastern Kansas, where it ranges in thickness from 34 to 60 inches. It is typically 18–23 inches thick in Oklahoma but locally attains a maximum of 48 inches. In southeastern Kansas near the Oklahoma line its average thickness is about 43 inches, and, farther north near the Missouri line, its average thickness is 32 inches. It is generally thinner in northeastern Kansas and in Missouri. The bed dips northwestward at about 20 feet per mile. In southeastern Kansas and adjoining parts of Oklahoma and Missouri, it has been mined on a substantial scale by strip-mining methods, and in southeastern Kansas it has also been mined by underground methods for a distance of about 6 miles downdip from the outcrop. It contains substantial resources farther downdip. In Labette County, Kan., the bed is reported to be 58 inches thick at a depth of 600 feet (Abernathy, 1944, p. 220). In Leavenworth County, Kan., it is 28 inches thick at a depth of 1,100 feet. In northwestern Craig County, Okla., a bed about 4 feet thick and 250–550 feet below the surface is a possible correlative of the Weir-Pittsburg (Trumbull, 1957, p. 357).

The bed has yielded roughly 80 percent of the cumulative coal production of Kansas.

### LOWER HARTSHORNE BED

The Lower Hartshorne bed contains the largest resources and is the most extensively mined bed in both Arkansas and Oklahoma. It is known

to be 28 inches or more thick and to be less than 3,000 feet below the surface over an area of 610 square miles in the two States; also, it is recognizable as a stratigraphic unit over an area of about 3,000 square miles. The area of accessible coal in this bed is smaller than that of important beds in other parts of the United States because the enclosing rocks are folded and locally steeply dipping. In Arkansas, therefore, the coal is preserved mainly in synclinal areas, and in Oklahoma the coal is accessible only in narrow belts parallel to steeply dipping outcrops.

In Arkansas the Lower Hartshorne bed attains a maximum thickness of 8 feet, and in Oklahoma it ranges in thickness from 2½ to 6 feet in the mined areas. The original identified resources in parts of the bed 28 inches or more thick total 1,864 million tons, according to data supplied by Haley (1960, p. 806, 808) and Trumbull (1957, p. 313).

### LOWER SUNNYSIDE BED

The Lower Sunnyside bed is the best known and most important commercial coal bed in Utah, and perhaps in the Western United States, because it is mined extensively for the manufacture of coke, which is used by the western steel industry. As mapped by Clark (1928, pl. 22) the Lower Sunnyside bed crops out for a linear distance of about 30 miles near the base of the Book Cliffs in the Sunnyside and Wellington quadrangles, Carbon County, Utah. Near the town of Sunnyside, where mining is concentrated, the bed ranges in thickness from 7 to 14 feet. It thins north and west of this area but is estimated to be at least 4 feet thick over an area of about 170 square miles in the Sunnyside quadrangle. Some of this coal is remote from the outcrop and is deeply buried. The thickest and most accessible coal is in a belt 2½ miles wide and 14 miles long near the outcrop, extending from about 4 miles south of Sunnyside to about 10 miles northwest of Sunnyside. In this restricted area of about 35 square miles the estimated original identified resources total about 230 million tons, according to data supplied by Clark (1928, p. 101–102). This represents an overall average coal thickness of 5.7 feet. Additional tonnage is, of course, present in the bed outside this choice belt and in other beds in the sequence of coal-bearing rocks.

### HIAWATHA BED

The Hiawatha bed, in Carbon and Emery Counties, Utah, is more extensive and contains larger accessible coal resources than the Sunnyside bed, but it is not as suitable for the manufacture of coke and is, therefore, mined for other purposes.

As mapped by Spieker (1931, pls. 31, 32), the Hiawatha bed crops out almost continuously over a linear north-south distance of 75 miles near the base of the east-facing cliffs of the Wasatch Plateau. Because of many reentrants and topographic and structural irregularities in the cliffs, the

actual outcrop distance is perhaps twice this amount. Near the town of Hiawatha, where the bed is actively mined, it is 7–20 feet thick. For 23 selected areas totaling about 220 square miles along the base of the Wasatch cliffs, where the local average thickness of the coal is 4 feet or more, Spieker (1931, p. 204–206) estimated that the bed contains 1,546 million tons of coal. For the 23 areas, this represents an overall average thickness of 6.1 feet. The Spieker report includes data on 8 additional areas totaling 20 square miles where the local average thickness of coal in the Hiawatha bed ranges from 2.2 to 3.1 feet and the estimated resources total 64 million tons. He also included data on other thick but less extensive beds.

Little is known about the thickness and continuity of the Hiawatha bed and other beds in the sequence of coal-bearing rocks downdip from the areas along the outcrop because this coal passes under the thick overburden of the Wasatch Plateau beyond the limits of present economic interest.

### D-WYODAK-ANDERSON BED

The Powder River basin of northeast Wyoming and southeast Montana contains many thick, closely spaced coal beds. The concentration of coal resources in this area is larger than that of any other area of comparable size in the United States. The large number and close spacing of coal beds, together with local and regional variations in thickness of coal and enclosing rocks, and other stratigraphic irregularities (including an obscure unconformity between the Fort Union Formation and the overlying Wasatch Formation), created problems in regional correlation that hampered early geologic mapping and establishment of reliable coal-bed nomenclature.

Of the many coal beds known in this area, the D–Wyodak–Anderson bed, which crops out in a northward-trending belt through Campbell County, Wyo., is the thickest and best known. It has been mined for many years at the Wyodak mine near Minturn, where it is 90 to 106 feet thick. Because of the conspicuous thick exposure at the Wyodak mine, the bed is now generally known as the Wyodak bed.

The Wyodak bed was first mapped by Dobbin and Barnett (1928, p. 14), who termed it the D bed and assumed incorrectly that it represented an eastward merging of the Roland bed and the underlying Smith bed of areas to the north and west. In a later study of the Spotted Horse field, which covers an area north and west of the Wyodak mine, Olive (1957, p. 13, pls. 4, 5) concluded that the Wyodak bed was a more likely correlative of the Anderson bed of the Spotted Horse field. The Anderson bed, which is about 300 feet lower stratigraphically than the Roland bed, is much thicker than the Roland bed and is continuous over a larger area. Studies in progress now indicate that the Anderson bed and the stratigraphically lower Canyon bed are both present in the Wyodak bed.

Studies of the Wyodak bed, as now defined, by Schell and Mowat (1972) and by Denson and Keefer (1974), have clearly established that it crops out continuously over a north-south airline distance of about 120 miles and that its correlatives persist in the subsurface to the deepest part of the Powder River basin. Throughout this large area, the Wyodak bed is generally 50 to 100 feet thick, but it thins locally to a minimum of 25 feet, and thickens locally to maximum of 150 feet. On the basis of these studies, the bed conservatively contains 100 billion tons of coal between the outcrop and the 2,000-foot overburden line. This is the largest tonnage in a single continuous coal bed anywhere in the United States. The outcrop of the bed to the 200-foot overburden line contains at least 15 billion tons of coal that is suitable for recovery by strip-mining methods, and plans for future expansion of coal mining in Wyoming are concentrated primarily along the outcrop of this bed.

### WADGE BED

The Wadge bed has been mapped for a linear distance of about 35 miles in Routt and Moffat Counties, Colo., and it is known to underlie an area about 300 square miles to a maximum overburden depth of 3,000 feet. The original identified resources in the bed in the known area of occurrence total 1,347 million tons (Bass and others, 1955, p. 210–223). The bed is actively mined by both underground and strip-mining methods to supply coal for the nearby Hayden powerplant and for powerplants in the Boulder and Denver areas. Where mined, the bed is 8–10 feet thick.

### RATON-WALSEN BED

The Raton-Walsen bed crops out discontinuously on the east edge of the Raton Mesa coal field from a point near Dawson, Colfax County, N. Mex., to central Huerfano County, Colo., a linear distance of about 70 miles.

In New Mexico the bed is known as the Raton or Willow Creek bed. It crops out discontinuously near the base of the Vermejo Formation from a point near Dawson northeastward to Raton, N. Mex., a linear distance of about 20 miles. At Koehler, N. Mex., where it is known as the Raton bed, it attains a maximum thickness of 12 feet 5 inches and is mined extensively (Wanek, 1963). At Van Houten, N. Mex., where it is known as the Willow Creek bed, it attains a maximum thickness of 13 feet and is also mined extensively (Lee, 1922). The Raton or Willow Creek bed thins rapidly from the areas of maximum thickness, and it is cut out locally by a sandstone and conglomerate zone at the base of the overlying Raton Formation. At other places in New Mexico, particularly near the Colorado State line, it has been intruded by basalt sills, and the coal has been burned or altered to graphite.

As a result of the local thinning, postdepositional erosion, and destruction by sills, the Raton or Willow Creek bed contains only modest

resources of a few hundred million tons, but it is one of the most important beds in New Mexico because the coal from this bed yields a high-quality metallurgical coke.

The Walsen bed of Colorado (locally known as the Lower Alamo, Cameron, Berwin, Bunker Hill, or Piedmont bed) occurs at about the same stratigraphic position in the Vermejo Formation as the Raton or Willow Creek bed and is believed to be its stratigraphic equivalent, although the two beds are not known to be stratigraphically continuous (Johnson, 1961). The Walsen bed crops out discontinuously on the northeast side of the Raton Mesa field from southernmost Las Animas County to central Huerfano County, Colo., a linear distance of about 50 miles. It maintains an average thickness of 3–3½ feet between these two points and is mined locally at many places. It has yielded more coal than any other bed in the Colorado part of the Raton Mesa field, largely because of its considerable areal extent and relatively uniform thickness, although it contains more ash and is less agglomerating than younger coals in the Vermejo and Raton Formations of Colorado.

### WHEELER A, B, C, AND D BEDS

The Wheeler bed is the thickest and most extensive bed in the Grand Hogback–Carbondale region, Garfield County, Colo. It is recognizable as a single, continuous thick bed for a linear distance of about 20 miles, beginning at a point about 10 miles northwest of New Castle and extending about 10 miles southeast of New Castle. At the northwest end of the identifiable outcrop, it is 30 feet thick. At New Castle, where it was formerly mined extensively to supply coal for the Denver and Rio Grande Railroad, it attains a maximum thickness in the range of 45–48 feet. The Wheeler bed thins southeast of New Castle, and at the point about 10 miles southeast of New Castle it is 14–18 feet thick (Gale, 1910, p. 109–128). South of this point, the Wheeler bed apparently splits into four beds, termed, from oldest to youngest, the A, B, C, and D beds. The C and D beds continue southward as recognizable units for less than 10 miles. The A and B beds continue southward as recognizable units for about 25 miles into the Coal Basin area, Pitkin County, which was described by Donnell (1962). The A, B, C, and D beds each range in thickness from about 4 to about 12 feet, and at any one place two or more of these beds are of thickness and quality suitable for mining.

The heat value and the rank of the coal in the Wheeler A, B, C, and D beds increase from north to south, and beginning roughly at the Garfield County line and extending southward into Pitkin County, the coal is suitable for the manufacture of metallurgical coke. Since the mid-1950's, coal from the A and B beds in the Coal Basin area and in the Thompson Creek area has been mined extensively for this purpose. In 1973 Pitkin County produced 780,000 tons of coal, most of which was moved by truck

to a railhead of the Rio Grande Railroad at Carbondale, Colo., and then by train to steel mills near Provo, Utah (Colorado Coal Mine Inspection, 1974, p. 17).

The Wheeler A, B, C, and D beds dip very steeply westward into the Piceance Creek basin, and the coal is 3,000 feet below the surface only a short distance from the outcrops. As a result, the estimated accessible resources in the Wheeler A, B, C, and D beds total only about 1 billion tons.

According to J. R. Donnell (oral commun., April 1967), stratigraphic correlations based on outcrop data and on data from wells drilled for oil and gas in the Piceance Creek basin indicate that the A bed of the Coal Basin area is stratigraphically equivalent to the Snowshoe bed of the Somerset-Paonia area and to the Cameo bed of the Grand Junction area. This equivalence suggests that there is a single bed, or group of closely related beds, at the same stratigraphic horizon on the east and south sides of the Piceance Creek basin that possibly extends at great depth under the entire 2,000-square-mile area of the Piceance Creek basin south of the Colorado River.

One of the most interesting deep occurrences of coal at the Wheeler–A–Snowshoe coal horizon is in a well drilled in sec. 13, T. 11 S., R. 92 W., in which the coal is 6,723 feet below the surface. There, the drill penetrated 14 feet of natural coke, underlain by an estimated 12–14 feet of quartz latite, which in turn is underlain by 12 feet of coal. This relation suggests that the quartz latite formed as a viscous igneous mass below the coal bed and, as it worked its way upward toward the surface, the mass spread out laterally as a tabular intrusive into a very thick coal bed, which offered the path of least resistance. As the intrusive cooled, the rising heat formed the natural coke in the upper part of the bed, whereas the lower part was not subjected to prolonged heating and was relatively unaffected.

### ROSLYN (NO. 5) BED

The Roslyn (No. 5) bed is but one of eight mapped coal beds in the Roslyn coal field, Kittitas County, Wash. However, it has yielded more coal than any other bed in the State and is, without question, the most important coal bed in the State. As described by Beikman, Gower, and Dana (1961, p. 21–33), the Roslyn (No. 5) bed ranges in thickness from 4.5 to 7 feet and contains, on the average, about 4.4 feet of clean coal. The bed originally covered a synclinal area of about 25 square miles, but about 2 square miles has been cut out and replaced by glacial outwash material, 12 square miles has been mined out, and 10 square miles remains unmined. Past mining has, in general, removed coal to an overburden depth of 1,000 feet, and most of the remaining coal lies between 1,000 and 3,000 feet below the surface. The coal at the northwest end of the field is of high-volatile A bituminous rank and is suitable for use in coking-coal blends.

Prior to January 1, 1960, the Roslyn (No. 5) bed had yielded 57 million tons of coal, and the resources remaining in the unmined part of the bed totaled 54 million tons. Very little mining has been done in other beds in the field. All mining in the Roslyn field ceased about 1964.

### PRODUCTION FROM THE IMPORTANT BEDS

Although production figures are not routinely collected for individual beds, it is obvious that the 23 beds just described have yielded the bulk of past United States production. The Pittsburgh bed alone has yielded about 21 percent of total cumulative United States production, and the 11 selected beds in the Appalachian basin have yielded at least 50 percent of total cumulative United States production. The No. 5 and the Herrin (No. 6) beds of the Illinois basin have yielded the bulk of production from the Illinois basin. The Weir-Pittsburg bed has yielded 80 percent of the total cumulative production of Kansas. The Lower Hartshorne bed has yielded the bulk of production in Oklahoma and Arkansas. The Lower Sunnyside and Hiawatha beds have probably yielded 75 percent of total cumulative production in Utah. The Wadge, Raton-Walsen, Wheeler, and equivalent beds have yielded at least 50 percent of the total cumulative production in Colorado. This subjective analysis permits the assumption that the 23 beds described above have yielded 75–80 percent of the cumulative past production of the United States.

## COST OF COAL

When coal is compared with most bulk commodities included in the wholesale price index, the increase in the cost of coal over the past 70 years has been relatively modest. As shown in figure 9, the least-squares trend line of the average value of coal f.o.b. (free on board) mines, expressed in constant dollars, has increased from $3.15 per ton in 1900 to $5.30 per ton in 1972. The increase over the period shown is modest because coal is widespread and abundant and because mining technology has improved substantially. The marked decrease in average cost in the late 1950's and the early 1960's reflects the steady increase in efficiency of strip-mining machinery and the concomitant increase in strip-mine production. In 1973 the average actual cost jumped to $8.42 per ton, and spot costs of several times this amount were recorded by the media. This rapid increase in cost was caused by increased demand for low-sulfur coal, inflation, and increased emphasis on coal miners' health and safety, and on spoil-bank reclamation.

Costs related to coal miners' health and safety and to spoil-bank reclamation are permanent increases and are not likely to be reduced appreciably. Costs related to demand in excess of productive capacity are, however, likely to be eliminated in the future as the productive capacity of the coal mining industry is increased. At such time, the average cost of

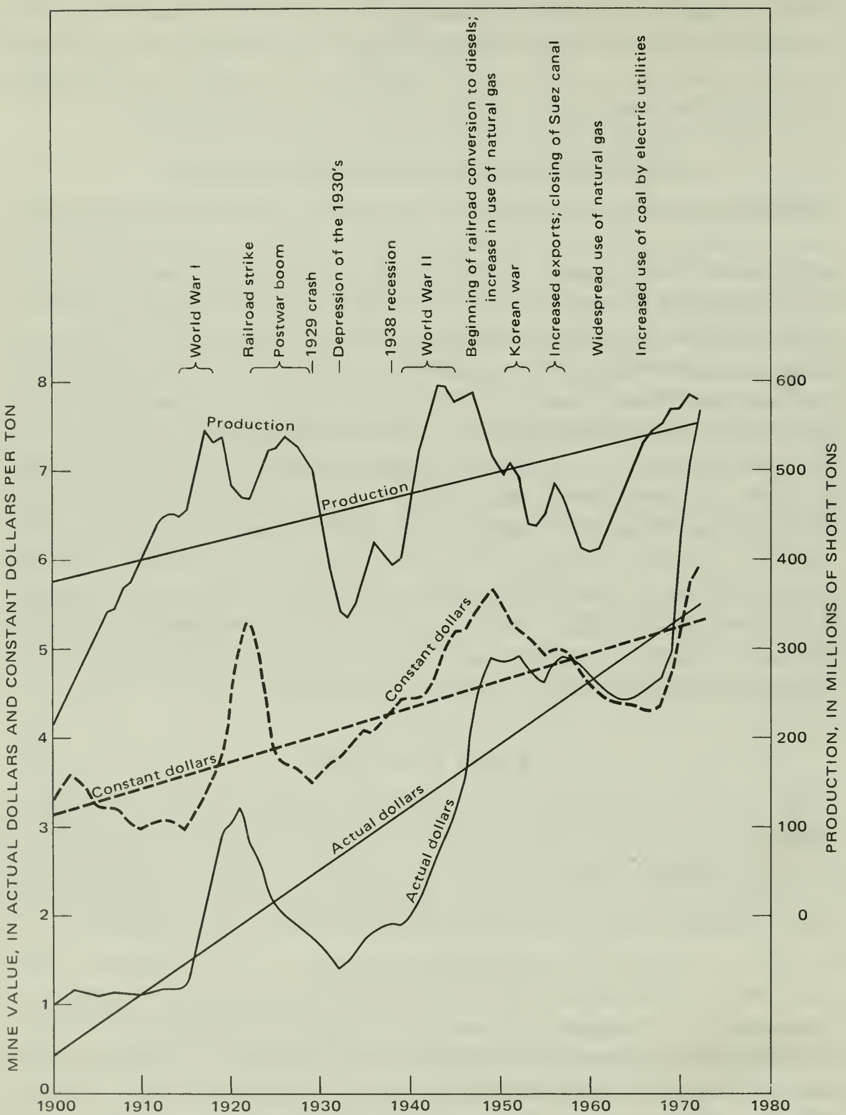



FIGURE 9.—Production and mine value of bituminous coal and lignite in actual and constant dollars (1957–59=100), expressed as 3-year moving averages and as least-squares trend lines, 1900–72.

coal, expressed in constant dollars, should move below the highs witnessed in the early 1970's to something approaching a slightly steeper least-squares trend line than that established by past experience.

## USES OF COAL

In addition to its primary use as an economical source of heat and energy, coal is a highly versatile chemical raw material, and it is the source or main component of hundreds of chemical products.

The accompanying table shows the major consumers of coal and several noteworthy changes in the pattern of use over the 30-year period covered by the table. Most conspicuous is the marked increase in use of coal by the fast-growing electric utility industry, from 12 percent of the total production of bituminous coal and lignite in 1943 to 70 percent in 1973. The rapid growth of the utility industry is impelled by growth in population, increased use of electric appliances, particularly air conditioning, and growth of the aluminum and uranium industries, which use electricity in processing and refining ore.

The steel industry has always been an important and consistent customer for coal. Most of the annual coke production, which is recorded separately in the table, is used by the steel industry, for about 1 ton of coke is needed to produce 1 ton of steel. Most of the coke is manufactured in byproduct ovens, which also yield the basic coal chemicals—coal gas, light and heavy oils, and tar. From these are derived ammonia, benzene, toluene, phenol, resins, plastics, paints, dyes, explosives, fertilizers, nylon, drugs, and many other chemical products.

*Consumption of bituminous coal and lignite in 1943, 1953, 1963, and 1973 by consumer class*

[Source: U.S. Bureau of Mines Minerals Yearbooks (1954, 1964, 1974a). In percent; Neg., negligible]

| Consumer class | 1943 | 1953 | 1963 | 1973 |
|---|---|---|---|---|
| Utilities | 12 | 26 | 51 | 70 |
| Steel industry: | | | | |
| Coke production | 17 | 26 | 19 | 17 |
| Steel and rolling mills | 2 | 2 | 2 | 1 |
| Manufacturing industries | 26 | 25 | 22 | 11 |
| Retail deliveries | 21 | 14 | 6 | 1 |
| Railroads | 22 | 7 | Neg. | Neg. |
| Total | 100 | 100 | 100 | 100 |

The manufacturing industries, which constitute the third most important consumer class, use coal primarily as a source of heat and power. Although use of coal by the manufacturing industries has declined slowly through the years, use of energy, and indirectly use of coal, by these industries has actually been increased through increased purchases of power from the electric utility companies.

Only a small amount of coal is now consumed for household heating because of the increased use of natural gas and oil for this purpose. Such

coal as is used for household heating is included under "Retail Deliveries," which accounted for only 1 percent of 1973 consumption.

Railroads, the largest single user of coal up to the end of World War II, turned almost completely to diesel locomotives during the 1950's, and since the early 1960's have accounted for less than 1 percent of coal consumption. The small amount of coal now consumed by the railroads is used primarily in powerhouses and shops.

Coal is of potential future importance as a subsidiary source of pipeline gas, liquid fuels, and lubricants, all of which can be synthesized from coal by various hydrogenation processes. A considerable amount of study and experimentation is being devoted to this aspect of coal technology. (See p. 82.)

Coal is also a direct potential source of methane ($CH_4$), which is the main component of natural gas. Methane is a volatile component of most coals and, in most underground bituminous coal mines, this gas seeps continuously from the coal into the mine workings where it becomes a fire and explosion hazard. High levels of ventilation and extraordinary precautions are necessary in underground mining of so-called "gassy" beds. Experiments by Fields and others (1973) on reduction of methane in coal prior to mining have been conspicuously successful. They employed many horizontal boreholes drilled into the coal from the bottom of a vertical shaft. The amounts of gas removed in these experiments suggest that consistent, large-scale use of the general method, aimed primarily at improving mine safety, could yield small commercial quantities of gas annually over a long period of time. (See Deul and others, 1973.)

Several nonfuel uses of coal, though quantitatively unimportant, are worthy of mention. Lignite mined in Amador County, Calif., is an important source of montan wax (Jennings, 1957, p. 158), and lignite mined in Texas is used in the manufacture of activated carbon. Bituminous coal mined in Carbon County, Utah, is a source of resins.

Weathered and slacked outcrops of lignite and subbituminous coal yield a commercial product known as leonardite, which is, or has been, mined on a small scale in North Dakota, Wyoming, Arkansas, and Texas, and used to control viscosity in oil-well drilling mud, to manufacture a water-soluble brown wood stain, as an organic combustible binder for taconite iron ore, and as a soil conditioner. As described by Fowkes and Frost (1960) and by Freeman and Fowkes (1968), leonardite ranges considerably in composition and properties but is characteristically high in humic acid and will absorb and retain water. It is relatively insoluble in distilled water but is readily soluble in alkaline water.

Swanson and Ging (1972) experimented with various mixtures of trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) and leonardite and ascertained that when the two are mixed in water in an ideal ratio of 1 part trona to 1½ parts leonardite, a rich, black, alkaline solution of humic material is obtained.

They suggest that a solution in this general range of compostion has possible application as a superior liquid soil conditioner or leaf spray and as a solvent for the secondary recovery of ore metals or for the removal of toxic metals from industrial wastes.

Ash from utility plants is used in the manufacture of concrete and cinder blocks, and crushed coal is being studied experimentally for use in road construction. Crushed coal and coal waste are used locally on icy roads in lieu of sand and salt.

Jet, an ornamental material in vogue in the 1890's, is a dense black variety of lignite that will take a polish. Some Pennsylvania anthracite of very uniform density will also take a polish and is used in the manufacture of jetlike ornamental objects.

Coal also contains several minor elements of great interest and potential economic importance, which are discussed below.

### EXPORTS

The United States has long been a net exporter of coal. During most recent years, exports have fluctuated between 50 million and 60 million tons annually, or 9 to 10 percent of total production. The exported coal is shipped primarily to Japan, Canada, and Western Europe. The major points of transshipment are Norfolk, Cleveland, and Baltimore. Minor points are New Orleans, Mobile, Philadelphia, and Los Angeles.

## MINOR ELEMENTS IN COAL

Coal contains small quantities of virtually all metallic and non-metallic elements, which were introduced into the coal bed in one or more of four different ways:

1. As inert material washed into the coal swamp at the time of plant accumulation.
2. As a biochemical precipitate from the swamp water.
3. As a minor constituent of the original plant cells.
4. As a later addition, introduced after coal formation, primarily by ground water moving downward and laterally.

When coal is burned, most of these elements are concentrated in the coal ash, but a few of the more volatile elements are emitted into the atmosphere. Coal ash is composed largely of the oxides of silicon, aluminum, iron, calcium, magnesium, potassium, sodium, and sulfur, which typically make up 93–98 percent of the total weight of the ash (Abernethy and others, 1969a). The remaining few percent of coal ash is made up of small individual amounts of many other elements, which differ in variety and quantity in different areas and beds. These elements are generally measured in parts per million or parts per billion and, for this reason, are termed minor elements, although they may not be minor elements in other contexts.

The minor elements in coal are of considerable interest because some may become of importance as a future resource, some are soil nutrients, and others may be pollutants. Most of the minor elements occur in coal in about the same concentration as their estimated average concentration in the Earth's crust, but 25–30 elements occur locally in greater concentration, and these have received the most study. A few elements—notably uranium, germanium, arsenic, boron, and beryllium—occur locally in vastly greater concentrations than their estimated average concentration in the Earth's crust; and others—including barium, bismuth, cobalt, copper, gallium, lanthanum, lead, lithium, mercury, molybdenum, nickel, scandium, selenium, silver, strontium, tin, vanadium, yttrium, zinc, and zirconium—occur locally in appreciably greater concentrations. Other elements of interest that generally occur in lower concentrations than their estimated average concentration in the Earth's crust include chromium, manganese, phosphorus, tellurium, thallium, titanium, and tungsten. The concentration of an element in excess of the estimated concentration in the Earth's crust, although a great interest and geologic significance, does not necessarily imply an economic or paramarginal concentration because that is determined by the concentration in typical commercial sources of the respective element.

Reports by Abernethy and Gibson (1963); Abernethy, Peterson, and Gibson (1969a, b); Zubovic (1966a, b); Zubovic, Sheffey, and Stadnichenko (1967); Zubovic, Stadnichenko, and Sheffey (1960a, b, c; 1961a, b; 1964; 1966); and by Sun, Vasquez-Rosas, and Augenstein (1971) summarize available information concerning minor elements in coal. A selected bibliography on trace elements in coal, applicable mainly to United States coals, was compiled by Averitt and others (1972).

Sulfur and several noteworthy minor elements in coal are discussed in the following paragraphs.

### SULFUR

Sulfur is an undesirable element in the use of coal. Like phosphorus, it lowers the quality of coke and of the resulting iron and steel products. It contributes to corrosion, to the formation of boiler deposits, and to air pollution. Its presence in pyritic shale and impure coal that form part of some spoil banks in the Eastern United States inhibits growth of vegetation. As sulfuric acid, it is the main deleterious compound in acid mine waters, which contribute to polution of eastern streams.

The sulfur content of coal in the United States ranges from 0.2 to about 7.0 percent, but the average in all coal is 1.0–2.0 percent. The sulfur in coal occurs as organic sulfur in combination with the coal-forming vegetal material; as a constituent of the iron sulfides, pyrite and marcasite ($FeS_2$); and as the secondary sulfates, hydrous ferrous sulfate ($FeS_4 \cdot 7H_2O$), and gypsum ($CaSO_4 \cdot 2H_2O$), formed by the weathering of the iron sulfides.

In the low-sulfur western coals, most of the sulfur, perhaps 50–95 percent, occurs as organic sulfur; most of the remaining amount occurs as a constituent of pyrite and marcasite; and only a small amount, depending on the degree of weathering, occurs as secondary sulfates.

In the high-sulfur eastern coals, most of the sulfur, perhaps 45–85 percent, occurs as a constituent of pyrite and marcasite, and the remainder occurs as organic sulfur and as the secondary sulfates. (See Walker and Hartner, 1966.)

As shown in the accompanying table, about 65 percent of the identified coal resources of the United States is low in sulfur (0–1.0 percent). Much of this low-sulfur coal is subbituminous coal and lignite concentrated in the Rocky Mountains and Northern Great Plains. About 15 percent of the identified resources is medium-sulfur coal (1.1–3.0 percent); and about 20 percent is high-sulfur coal (3.0 percent or more). Much of the medium- and high-sulfur coal is concentrated in the bituminous coal of the Central and Eastern United States.

*Distribution, in percent, of identified United States coal resources according to rank and sulfur content*

[Data from DeCarlo, Sheridan, and Murphy (1966)]

| Rank | Sulfur content (percent) | | |
|---|---|---|---|
| | Low 0–1 | Medium 1.1–3.0 | High 3+ |
| Anthracite | 97.1 | 2.9 | .... |
| Bituminous coal | 29.8 | 26.8 | 43.4 |
| Subbituminous coal | 99.6 | .4 | .... |
| Lignite | 90.7 | 9.3 | .... |
| All ranks | 65.0 | 15.0 | 20.0 |

## RESEARCH ON REMOVAL OF SULFUR

The iron sulfide minerals pyrite and marcasite have a high specific gravity, and most of this material can be removed from coal by various washing and cleaning procedures. (See Deurbrouck, 1972.) The sulfates, which are present in the zone of weathering and are not present in fresh-mined coal, have a lower specific gravity and are less easily removed. The organic sulfur is part of the coal substance and cannot be removed by washing. About 65 percent of all coal mined in the United States is cleaned to remove pyritic and inert material before use. However, in spite of such large-scale cleaning, the average sulfur content of all coal used in the United States is still nearly 2 percent.

Current efforts to reduce the sulfur content of coal and of flue gas take several forms:

1. Much research is in progress on methods to remove $SO_2$ and $SO_3$ from flue gas. This removal can be done in theory and in the labora-

tory by several well-known chemical processes, and the technical problems inherent in the large-scale commercial application of chemical processes, although now intractable, are likely to be solved in the near future. (See Haas, 1973; Hyne, 1972; Oil and Gas Jour., 1972b, c; Electrical World, 1972a, b; Campbell and Ireland, 1972; Rosenbaum and others, 1973.)

2. Meanwhile, the search for low-sulfur coal has been intensified, particularly in the Eastern States, and the use of lower sulfur coal has been increased. A few older coal-burning utility plants in the Midwest have converted from high-sulfur local coal to low-sulfur Rocky Mountain coal. This substitution has required payment of transportation cost of $3 to $5 per ton and acceptance of the lower heat content of Rocky Mountain coal. Such high transportation costs obviously will intensify research efforts mentioned in item 1 above.
3. Much research is in progress on methods to produce a high-Btu, sulfur-free pipeline gas or liquid from coal. This is also a technical possibility believed by many to be within early practical achievement. (See Bodle and Vyas, 1974; Boyd, 1974; Frank and Schmid, 1973; Goodridge, 1974; Harris and Davison, 1973; Hatten, 1974; Mehta and Crynes, 1973; Office of Coal Research, 1972, 1973, 1974; Oil and Gas Jour., 1972a, 1973; Osborn, 1974; Siegel and Kalina, 1973.) Success in meeting this objective on a commercial scale has the multiple advantage of lowering the costs of long-distance transportation of energy, eliminating the sulfur problem, augmenting declining resources of natural gas, reducing dependence on foreign sources of oil and gas, and, ultimately, permitting use of high-sulfur eastern coal.

These varied approaches to the sulfur problem suggest that the amount of sulfur released to the atmosphere by the burning of coal will ultimately be greatly reduced.

## URANIUM

Uranium occurs locally in coal as compounds or complexes intimately associated with the organic constituents. In a few localities the uranium content is high enough to suggest the possibility of mining the coal as uranium ore. As a result, a large amount of study has been directed toward such coals (Kehn, 1957; Page and others, 1956, p. 405–444, particularly the bibliographies on p. 410, 418, 430, 438, 444; Vine, 1962).

Some beds of lignite and carbonaceous shale in southwestern North Dakota and northwestern South Dakota contain an average of 0.18 percent uranium, 0.3 percent molybdenum, 0.09 percent phosphorus, and 0.01 percent vanadium. These figures apply to the full thickness of the carbonaceous beds, which contain an average of about 45 percent ash. These rocks also contain anomalously high amounts of arsenic,

germanium, selenium, cobalt, and zirconium (Denson and Gill, 1956; Denson and others, 1959).

Carbonaceous material has a strong chemical affinity for uranium, and uranium in solution is readily adsorbed or precipitated by contact with lignite or carbonaceous shale. The uranium and associated elements in the Dakota lignite deposits were probably leached by ground water from overlying tuffaceous rocks and carried downward and precipitated on and in the underlying lignite.

Near the common corner of North Dakota, South Dakota, and Montana, a 13,000-square-mile area of uranium-bearing lignite has been delineated by members of the Geological Survey. (See Denson and Gill, 1956; Denson and others, 1959.) On the basis of these findings, commercial recovery of uranium from the lignite was attempted at four localities in North and South Dakota during the period 1963–65. The thin, impure uranium-bearing lignite beds at these localities were strip mined and concentrated by burning in open piles or by roasting in rotary kilns. Three tons of impure lignite yielded about 1 ton of ash. The ash was shipped for final concentration and recovery of the uranium to plants at Grants, N. Mex., Rifle, Colo., and Edgement, S. Dak. (See Mitchell, 1965.) In the 3-year period 1963–65, about 150,000 tons of uraniferous lignite containing $U_3O_8$ valued at about $9 million was mined, concentrated, and processed. The general area contains additional comparable material with a potential mined value of about $30 million.

## GERMANIUM

Most of the germanium produced in the United States is a byproduct of zinc smelting. The expanded use of germanium as a semiconductor in crystal diodes, transistors, and rectifiers in the period following World War II greatly stimulated interest in coal as a secondary source of this element. (See Stadnichenko and others, 1953; Headlee and Hunter, 1951; Schleicher, 1959.) Where germanium is present in a coal bed it is concentrated locally in the top and bottom layers, or just above a thick parting, and is much more abundant in the bright bands (vitrain) than in the dull bands.

The highest concentration of germanium discovered to date in the United States has been in coalified logs and pieces of woody coal in rocks of Cretaceous age in the Atlantic Coastal Plain. Some of these logs contain as much as 7.5 percent germanium in the ash. The commercial coal richest in germanium is the Lower Kittanning bed in eastern Ohio. The germanium is concentrated in the lowermost layer of this bed. Samples of this layer contain a maximum of 0.2 percent germanium in the ash, and the ash constitutes 3.54 to 6.86 percent of the coal (Stadnichenko and others, 1953, p. 1, 9).

A 2-inch layer of Nodaway coal from Greenwood County, Kans.,

contains 0.99 percent germanium in the ash, and the ash constitutes 10.98 percent of the coal (Schleicher, 1959, p. 174).

Following the period of intensive study in the late 1950's, interest in germanium in coal slackened because of increasing competition of silicon as a semiconductor and because of increased efficiency in the use of germanium. Since the late 1950's, byproduct and imported germanium have supplied the commercial demand.

## ARSENIC

Arsenic is a common, but only locally an abundant, minor element in coal. A table of 13 analyses of arsenic in whole coal from worldwide sources, prepared by Sun, Vasquez-Rosas, and Augenstein (1971, p. 23), shows arsenic contents ranging from 0 to 2,000 ppm (parts per million). The mean of the minimum figures in the compilation is 0.3 ppm, and the mean of the maximum figures is 98 ppm. The arsenic content of bituminous coal in Germany ranges from 1 to >50 ppm (Kirsch, Pollman, and Ottemann, 1968), and the maximum arsenic content of bituminous coal ash from West Virginia is 570 ppm (Headlee and Hunter, 1955).

The arsenic in coal is contained mainly in pyrite ($FeS_2$) and to a lesser extent in clay minerals and organic matter. Highly pyritic bituminous coals of Paleozoic age are, therefore, more likely to contain higher concentrations of arsenic than other coals. The arsenic content of low-sulfur coals used by major powerplants in the Southern Rocky Mountains ranges from >1 to 4 ppm (U.S. Department of the Interior, 1972, p. 39). These amounts are less than the relatively low concentration of arsenic in soil or in the Earth's crust, which is estimated to be about 5 ppm.

Arsenic is volatilized at the usual temperatures of coal combustion and tends to precipitate in the superheater tubes of boilers, in stacks and dust chambers, and in fly ash.

The widespread practice of washing or mechanically cleaning bituminous coal of the Eastern United States to remove pyrite and inert material tends to greatly reduce aresenic emission, and the amount emitted by powerplants will be further reduced by the more widespread use and future improvement of equipment designed to reduce emission of particulate matter and sulfur.

## BORON

The concentration of boron in certain coals is much higher than the apparent concentration of boron in the Earth's crust. Analyses of the ash of 319 samples of low-rank coal from Texas, Colorado, North Dakota, and South Dakota showed an average of about 0.1 percent boron, and individual beds elsewhere have been reported to contain as much as 2 percent boron in the ash (Deul and Annell, 1956, p. 163–164).

Boron is a minor constituent of living plants and is concentrated in the surface and near-surface soils supporting the growth of such plants (U.S.

Geological Survey, 1964, p. A183). Much of the boron in coal certainly was contained in the original plant constituents.

## BERYLLIUM

Beryllium is present in virtually all coal beds in amounts ranging from 0.1 ppm to 31 ppm. The average beryllium content in 1,342 samples, in the richest bed, and in the richest part of a bed is shown in the accompanying table.

*Concentration of beryllium in United States coals*
[From Stadnichenko, Zubovic, and Sheffey (1961, p. 265–275, 277, 285)]

| Sample | Beryllium in coal (ppm) | Ash in coal (percent) | Beryllium in ash (ppm) |
|---|---|---|---|
| Average of 1,342 samples | 3.6 | 7.74 | 46 |
| Richest bed[1] | 31 | 2.85 | 1,100 |
| Richest part of bed[2] | 24 | 1.0 | 2,400 |

[1]Harlan (B) bed, International Harvester No. 2 mine, Benham, Harlan County, Ky. (Sample No. Ky–IH).
[2]Block 1–b from bed cited above.

The values shown in the table are substantially higher than the concentration of beryllium in the Earth's crust, which is estimated to be 2 ppm.

As discussed by Stadnichenko, Zubovic, and Sheffey (1961), the beryllium was introduced at the time of coal formation and was derived from nearby eroding areas of beryllium-bearing rock. Notable areas of beryllium enrichment in the Eastern United States are in Indiana, eastern Kentucky, and southern West Virginia. With minor local exceptions, the beryllium concentration is generally lower in coal in the Rocky Mountain and Northern Great Plains regions.

The beryllium is concentrated in vitrain and in the coal substance and was either accumulated by plants, adsorbed on the colloidal organic particles, or fixed by the formation of beryllium-organic complexes with the decomposition products of plant tissues. There is no appreciable beryllium in the inert constituents of coal, as evidenced by the fact that a coal low in ash typically shows a greater concentration of beryllium in the ash than a coal high in ash. This relation, which is clearly shown in the table, suggests that future study should be directed toward low-ash coals now being mined in areas where general enrichment in beryllium has been noted.

## GOLD

Published reports on coal and on trace elements in coal suggest very strongly that gold is concentrated locally in some coal beds. The information bearing on this possibility was summarized in the previous edition of this report (Averitt, 1969, p. 78–79), and it led to sampling of

coal from three promising localities—the Cambria field, Crook and Weston Counties, Wyo.; the Kemmerer field, Lincoln County, Wyo.; and the Wales field, Sanpete County, Utah. Fire assays on these samples failed to disclose gold (less than 0.1 ppm in the ash). The samples were not analyzed by the neutron activation method, which might have disclosed gold in insignificantly small quantities not disclosed by the fire assays. The results of the assays raise doubt as to the accuracy of some of the older published observations (James D. Vine, oral commun., 1972).

## INDUSTRIAL ROCKS AND MINERALS ASSOCIATED WITH COAL

In parts of all coal-field areas, shale, sandstone, and limestone are closely associated with coal and may be of considerable local industrial importance, particularly if they can be extracted with the coal at relatively low cost.

The clay zone (or seat earth) that commonly underlies coal is mined locally for use in making refractory brick. Where this material is of suitable composition and thickness, it may be of more economic value than the overlying coal. Sandstone may be useful as a building and construction material; limestone may be useful as road metal and as an ingredient in cement; and clay and shale may be useful for the manufacture of brick, or as ingredients in cement.

The possibilities of recovering industrial rocks and minerals associated with coal were summarized in a comprehensive report prepared by the Office of Coal Research (1965).

## OWNERSHIP OF COAL LANDS

The coal lands of the United States are held by several broad classes of owners, including the Federal and State Governments, mining and manufacturing corporations, railroads, Indian tribes, and private individuals. Information concerning the ownership of the surface, coal, and mineral rights for any individual tract of land can be ascertained fairly readily from the records of appropriate county, State, or Federal agencies. However, no overall study of land and mineral ownership for the United States as a whole has been made because of the size, complexity, and cost of the task, and because of day-to-day changes in ownership. A few facts concerning the distribution of ownership in broad categories, or in selected areas, are summarized in the following paragraphs.

Most of the coal lands in the East and in the Mississippi Valley region are privately owned. In the Appalachian basin, many large tracts of coal land are held by mining, manufacturing, or landholding corporations. In this area, also, the three or four main eastern coal-hauling railroads own

some coal lands along their rights-of-way. In areas remote from transportation facilities, individual counties own some coal acreage, most of which was acquired during the depression of the 1930's through failure of the owners to keep up real estate tax payments. The Federal Government has only modest holdings of coal rights in the Eastern States. These rights are estimated to total somewhat more than 1 million acres, concentrated in forests and Government installations and reservations (E. H. Montgomery, U.S. Bureau of Land Management, oral commun., July 1974).

Most of the coal lands in the Rocky Mountain and Northern Great Plains regions are owned by the Federal Government. In disposing of land in the public domain under the provisions of the "Coal Lands Act" of 1873 and prior legislation, coal rights were included in the purchase price of homesteaded land, subject only to restriction as to the acreage held by an individual or small association. In 1906 all known coal-bearing lands remaining in the public domain were temporarily withdrawn from private entry, and there followed, between 1907 and 1910, a series of additional withdrawals and acts that eventually separated surface and coal rights and established Federal claim to the coal rights. (See Public Land Law Review Commission, 1968, p. 724–730.) After this major change in philosophy, individuals could, under the provisions of the homestead laws, obtain title to the land surface, but not to the underlying coal. In fact, the Federal Government appraised each tract of homesteaded land for its coal value and fixed a fee commensurate with this value. The homesteader could, therefore, obtain coal rights on the homesteaded land upon payment of the additional fee. This practice was terminated by passage of the Mineral Leasing Act of February 25, 1920, and thereafter the Federal Government retained coal rights on all lands classified as valuable for coal when such lands were sold. Although coal rights on thousands of acres of coal-bearing land were relinquished or sold to private owners prior to 1920, the Federal Government is still the largest owner of coal lands or coal rights in the Rocky Mountain and Northern Great Plains regions.

Township plats (master title plats and coal plats) of most areas in the Rocky Mountain and Northern Great Plains regions available in offices of the U.S. Bureau of Land Management show past disposal of Government coal lands. In addition to the township plats, the Bureau of Land Management has published a series of Surface Minerals Management Maps at the scale of 1 inch to 2 miles for many areas in the Rocky Mountain and Northern Great Plains regions. These maps show Federal, State, Indian, and private ownership of surface and mineral rights as of the date of preparation. The Bureau of Land Management has also prepared special land and mineral ownership maps for the Northern Great Plains Resources Program. One of these maps shows surface ownership at the scale of 1:1,000,000 for parts of Montana, Wyoming, North

Dakota, and South Dakota. Another set of Minerals Management Maps at the scale of 1:500,000 show Federal ownership of minerals for the same general area.

As shown in the accompanying table, ownership of coal lands and coal rights by the Federal Government in the Rocky Mountain and Northern Great Plains regions ranges from a high of 82 percent in Utah to a low of 25 percent in North Dakota and is probably 55–60 percent for the 8-State region as a whole.

The percentages shown in the table are provisional estimates based on incomplete data; they are intended only to show broad general relations, and they are not applicable to acreages or tonnages of coal reported for areas smaller than an individual State.

*Federal ownership of coal lands and coal rights in the Rocky Mountain and Northern Great Plains States*

[Modified from: U.S. Bureau of Land Management, 1974, p. I–208]

| State | Percent |
|---|---|
| Montana | 75 |
| Wyoming | 65 |
| North Dakota | 25+ |
| South Dakota | Not available. |
| Utah | 82 |
| Colorado | 53 |
| Arizona | Small. |
| New Mexico | 59 |

In the early days of construction of the transcontinental railroads, the railroad companies received as a form of subsidy considerable areas of land, including coal rights, parallel to the rights-of-ways. (See U.S. Department of the Interior, 1931, p. 405–431.) The Northern Pacific Railroad, for example, received odd-numbered sections in a checkerboard pattern for a distance of 40 miles on both sides of the right-of-way. The Union Pacific and Santa Fe Railroads received odd-numbered sections for a distance of 20 miles on both sides of the rights-of-ways.

Subsequently, the railroads made many exchanges of land to accommodate homesteaders, States, and the Federal Government. The grant to the Santa Fe Railroad, for example, resulted in ownership of coal lands in the southern part of the San Juan basin of New Mexico south of the Navajo Indian Reservation. At a later date, when it became desirable to enlarge the reservation southward, the Santa Fe Railroad lands in the path of the expansion were, by request, exchanged for a relatively solid block of coal land of comparable acreage east of the reservation. The railroads sold some land, including coal rights, to early settlers, and they sold much larger amounts, exclusive of coal rights, to later settlers. As a result of exchanges and sales, the current pattern of coal ownership by the western railroads differs considerably from that of the original grants, but

the western railroads as a group still hold the second largest acreage of coal land in the Rocky Mountain and Northern Great Plains regions.

When the Western Territories were admitted to Statehood, substantial amounts of coal-bearing land were transferred to State ownership through grants of one to four sections (typically two) in each township. The income from these sections was intended to provide support for the State school systems, hence, the appellation "School Section." Through this transfer and other means, the Western States as a group hold the third largest acreages of coal lands in the Rocky Mountain and Northern Great Plains regions.

In Montana, Arizona, New Mexico, and Oklahoma, fairly large acreages of coal land are on Indian reservations. This land is leased by the individual tribes with advice by the U.S. Bureau of Indian Affairs.

In Washington and Oregon the percentage of coal land owned privately is somewhat higher than it is in the Rocky Mountain and Northern Great Plains regions, but even in these States the Federal Government owns substantial acreages of coal land.

The information available on the distribution of coal and on ownership of coal rights leads convincingly to the conclusion that it would be virtually impossible for any individual, corporation, or cartel to obtain a monopoly on coal or even to significantly influence the price. The reasons for this conclusion are (1) coal is widespread and abundant in the United States; (2) ownership is broadly distributed; (3) the Federal and State Governments own substantially more than half the coal lands and coal rights in the Rocky Mountain and Northern Great Plains regions; (4) leases of Federal coal rights have practical acreage limitations for holdings in any one State; and (5) most major consumers of coal have substantial coal holdings.

A few major consumers of coal, most notably certain long-established or smaller electric utility companies, do not rely on ownership of coal to insure future supplies. Instead, these companies purchase coal on contracts from independent coal-producing companies and rely on purchasing power and on competitive bidding to insure low prices. This practice, which is obviously advantageous in most phases of the economic cycle, is highly disadvantageous in years when demand for coal exceeds productive capacity, such as the years during World Wars I and II and during the period beginning in 1970. (See fig. 9.) Partly for this reason and partly because of the increase in size of electric generating plants, most of the very large plants constructed in the late 1960's and early 1970's either own coal outright, or have entered into long-term contractual agreements with coal producers and with coal-hauling railroads.

In the past, title to Government-owned coal in the Rocky Mountain and Northern Great Plains regions could be obtained (1) by application for a prospecting permit with a preference right to a lease upon discovery

of a commerical deposit, or (2) at a competitive lease sale (U.S. Bureau of Land Management, 1972). In the late 1960's and early 1970's, however, burgeoning interest in low-sulfur coal, in low-cost strippable coal, and in coal in large blocks adequate to supply the long-term needs of large powerplants or coal gasification plants led to increased purchase, leasing, and speculative activities in these regions. As a result, the amount of coal privately owned or under lease may, in some areas, be in substantial excess of immediate or near future needs. The increased activity took place shortly before and at the same time as the increase in national concern over the environment.

On February 17, 1973, the Secretary of the Interior announced a new coal-leasing policy intended to insure maximum protection of the environment, orderly and timely resource development, and a fair return to the Government and to the public for disposal of rights to Federal coal lands. The main features of the new policy are as follows:

1. Prospecting permits will not be issued until further notice (Secretarial Order No. 2952).
2. For the near term, coal leases will be issued only on the basis of demonstrated need and insurance of full protection of the environment.
3. The coal leasing program of the future will be guided by advance land-use planning, including environmental studies on both a regional and local basis, to insure that national energy needs are met on a timely and effective basis.

## WORLD COAL RESOURCES

As here estimated, the original identified coal resources of the world total 6,390 billion tons; the additional hypothetical resources total 10,230 billion tons; and the two categories combined total 16,620 billion tons. The distribution of this tonnage by continents is shown in table 9.

These figures, which are at best only gross approximations, were obtained by analysis and extrapolation of estimates from about 50 countries. Extrapolation was required to obtain continent totals because estimates for most countries are not comparable. The estimates differ primarily because of differences in the point of view of the estimators and secondarily because of differences in the minimum thickness of coal included, the maximum thickness of overburden considered, and the amount of geologic and exploratory information available.

The differences in point of view result from the fact that coal is an abundant bulk commodity in most parts of the world, and annual production is typically only a very small part of the total potentially available in the ground. Economic interest is thus centered only on the thicker and more accessible beds, whereas long-range national planning and good resource management require consideration of thinner and less accessible beds that may be needed in the future. For some countries,

TABLE 9.—*Estimated total original coal resources of the world, by continents*[1]
[In billions ($10^9$) of short tons]

| Continent | Identified resources (1) | Estimated hypothetical resources (2) | Estimated total resources (3) |
|---|---|---|---|
| Asia[2] | [3]4,000 | 7,000 | [4]11,000 |
| North America | 1,900 | 2,500 | 4,400 |
| Europe[5] | 300 | 500 | 800 |
| Africa | 90 | 160 | 250 |
| Oceania[6] | 70 | 60 | 130 |
| South and Central America | 30 | 10 | 40 |
| Total | 6,390 | 10,230 | 16,620 |

[1]Original resources in the ground in beds 12 in. or more thick, and generally less than 4,000 ft below surface but includes small amounts between 4,000 and 6,000 ft.
[2]Includes European U.S.S.R.
[3]Includes about 2,300 billion short tons in the U.S.S.R. (Mel'nikov, 1972, p. 78).
[4]Includes about 9,500 billion short tons in the U.S.S.R. (Mel'nikov, 1972, p. 79).
[5]Includes Turkey.
[6]Australia, New Zealand, New Caledonia.

particularly the highly industralized countries that make extensive use of coal, estimates are available for resources in several categories according to thickness of coal and overburden and according to several points of view. For other countries, however, only one estimate is available.

The figures for identified resources in column 1 of table 9 are based reliably on factual data and are conservative. The figures for hypothetical resources (col. 2) and for total estimated resources (col. 3) are less reliable but are based on opinions of competent observers and on extrapolations from the figures in column 1.

Most of the figures in column 1 and some in column 3 were taken from the World Power Conference Survey of Energy Resources (Parker, 1962; 1968), which specify that the tonnages of hard coal shall be in beds "containing not less than 30 cm. [12 in.] of merchantable coal and situated not more than 1,200 metres [3,937 ft] below the surface * * *"; and that tonnages of lignite and brown coal shall be in beds "containing not less than 30 cm. [12 in.] of merchantable lignite or brown coal and situated not more than 500 metres [1,640 ft] below the surface * * *." However, many of the individual estimates making up the totals in column 1 are based on different assumptions. The estimates for the United States, for example, are based on a minimum thickness of 14 inches for anthracite and bituminous coal, on 30 inches for subbituminous coal and lignite, and on a maximum overburden of 6,000 feet. By contrast, the estimates for brown coal in West Germany include only measured reserves in beds suitable for recovery by opencut mining.

Most of the tonnage shown in column 1 lies between 0 and 2,000 feet below the surface, and only a small amount lies between 2,000 and 4,000 feet. The bulk of that listed in column 3 also lies between 0 and 2,000 feet, but larger amounts are present between 2,000 and 4,000 feet, and a small additional amount lies between 4,000 and 6,000 feet. Because most of the

coal in the world occurs in shallow structural basins, the amount potentially present decreases with each 1,000-foot increase in depth, and the amount potentially present below 3,000 or 4,000 feet is small as compared with the larger amounts at shallow depth.

Some of the figures used in obtaining the continent totals in column 1 are for remaining resources in the ground as of various dates in the past; others are for original resources. Most of the figures used to obtain the continent totals in column 3 are for original resources. The bulk of the tonnage in table 9 is properly classified as original resources.

The figures for the United States as recorded in table 3 are included in the totals for North America in table 9. On the basis of identified resources, the United States contains about one-fourth of world resources. On the basis of total resources, the United States contains about one-fifth of world resources.

Table 9 shows clearly that Asia contains most of the world's potential resources. This tonnage is concentrated in the U.S.S.R. and in the People's Republic of China, both of which are important coal-producing countries. Other continents lag behind Asia in a sequence of rapidly decreasing tonnages. In Europe, the coal resources have been well documented by many years of detailed geologic mapping and extensive exploration, and economic parameters have been applied with increasing frequency to the identified category. As a result, much of the tonnage classed as hypothetical is in beds too thin or too deeply buried to be mined economically. In Africa, coal in the hypothetical category is, in considerable part, too impure to be mined economically. However, much coal-bearing rock in Africa is concealed by younger rock, and estimates of resources in all categories are subject to increase in the future. Finally, table 9 shows that Oceania and South and Central America contain small resources as compared with the rest of the world but that the quantities assumed to be present are sufficient to justify continued exploration and development.

These revised estimates differ markedly from those presented in the report of the Twelfth International Geological Congress (Internat. Geol. Cong. 12th, 1913), but, where more recent information is not available, the older report contains much useful information on the geology and occurrence of coal in various countries.

## WORLD COAL PRODUCTION

In 1972 world coal production totaled 3,160 million short tons, of which the U.S.S.R. contributed 20 percent, the United States 19 percent, the People's Republic of China 14 percent, and Western Europe 13 percent. The remaining 34 percent was produced in many smaller countries and regions (U.S. Bureau of Mines Minerals Yearbook, 1972, p. 64–65).

The coal production of the People's Republic of China has increased

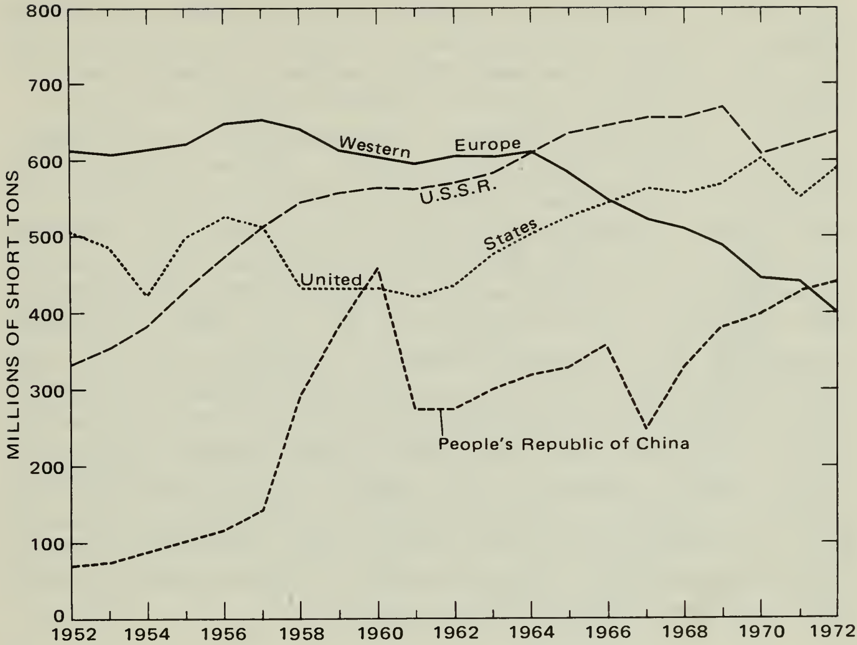



FIGURE 10.—Coal production in the U.S.S.R., Western Europe, the United States, and the People's Republic of China, 1952–72. (Source: U.S. Bureau of Mines Minerals Yearbooks, 1952–72.)

steadily in recent years, as shown in figure 10, whereas that of Western Europe has declined. During the same period, coal production of the United States and the U.S.S.R. has remained fairly constant.

Certain features of the trend lines shown on figure 10 merit comment. The level line for Western Europe prior to 1964 and the decline thereafter reflect difficulty in maintaining past levels of coal production because of gradual depletion of the thicker and more accessible coal beds and increased reliance on imported petroleum and natural gas and on atomic energy.

The pronounced increase in coal production in the U.S.S.R. between 1952 and 1958 represents a period of strong industrial growth based on use of coal. The leveling and slower growth rate since 1958 reflect increased use of waterpower and of petroleum and natural gas. As a result of continued discoveries of petroleum and natural gas, the U.S.S.R. is now self sufficient in both commodities and is a net exporter of petroleum and petroleum products.

The upward trend in the production line for the United States beginning in 1962 represents substantially increased use of coal by the electric utilities, brought about by lower cost of strip-mined coal, lower transportation costs in unit trains, and improvements in efficiency of burning coal. With increase in cost and decrease in availability of residual

crude oil and natural gas, use of coal by the electric utilities is expected to increase. Use of coal for the manufacture of synthetic gas for household use is also expected to increase. The trend line for United States coal production is, therefore, expected to continue upward in the future.

The very pronounced increase in coal production in the People's Republic of China during 1957–60 reflects a planned program—The Great Leap Forward—made possible in part by technical assistance from the U.S.S.R. The sharp decline after 1960 is the result of closing uneconomical mines opened hastily during The Great Leap Forward and the withdrawal of technical assistance by the U.S.S.R. Wang (1964, p. 1293) suggested that the figures for 1959 and 1960 are probably exaggerated about 20 percent because of unrealistic claims and the inclusion of impure coal. If this is so, the actual 1960 coal production in China may have been on the order of 350 million tons. The more normal growth rate between 1961 and 1966 represents normal improvements without outside assistance and with regard to economic feasibility. The decline in production in 1967 was caused by political unrest during the peak of the Red Guard movement (Wang, 1968, p. 200–201). Subsequent marked improvement in production reflects a return to political stability and a period of substantial economic growth.

## RELATION OF COAL IN THE UNITED STATES TO OTHER FORMS OF ENERGY

The United States produces and consumes prodigious quantities of energy. The mineral fuels, waterpower, and nuclear power produced in 1972, for example, contained the heat equivalent of 13 horsepower of mechanical energy per person operating continuously 24 hours per day and 365 days per year, and the amount consumed was equivalent to 15 horsepower. The figure for energy produced includes modest amounts of domestic coal mined for export, and the larger figure for energy consumed does not include coal mined for export but does include substantial amounts of imported petroleum and residual crude oil.

As shown in figure 11, production of energy in the United States has increased at an extraordinary rate since the depression of the 1930's and has doubled since the mid-1950's. In spite of this increase in domestic production of energy, annual consumption has exceeded production since the mid-1950's at a steadily increasing rate, which reached undesirable proportions in the early 1970's. This upward trend in energy consumption is impelled by a variety of factors, including population growth, increased per-capita use, increased efforts to reduce pollution, and increased use of energy in the production of agricultural products. Efforts at conservation of energy and recycling of metals, glass, plastics, paper, and garbage may reduce the rate of increase in use of energy, but they are not likely to reduce the upward trend in the foreseeable future.

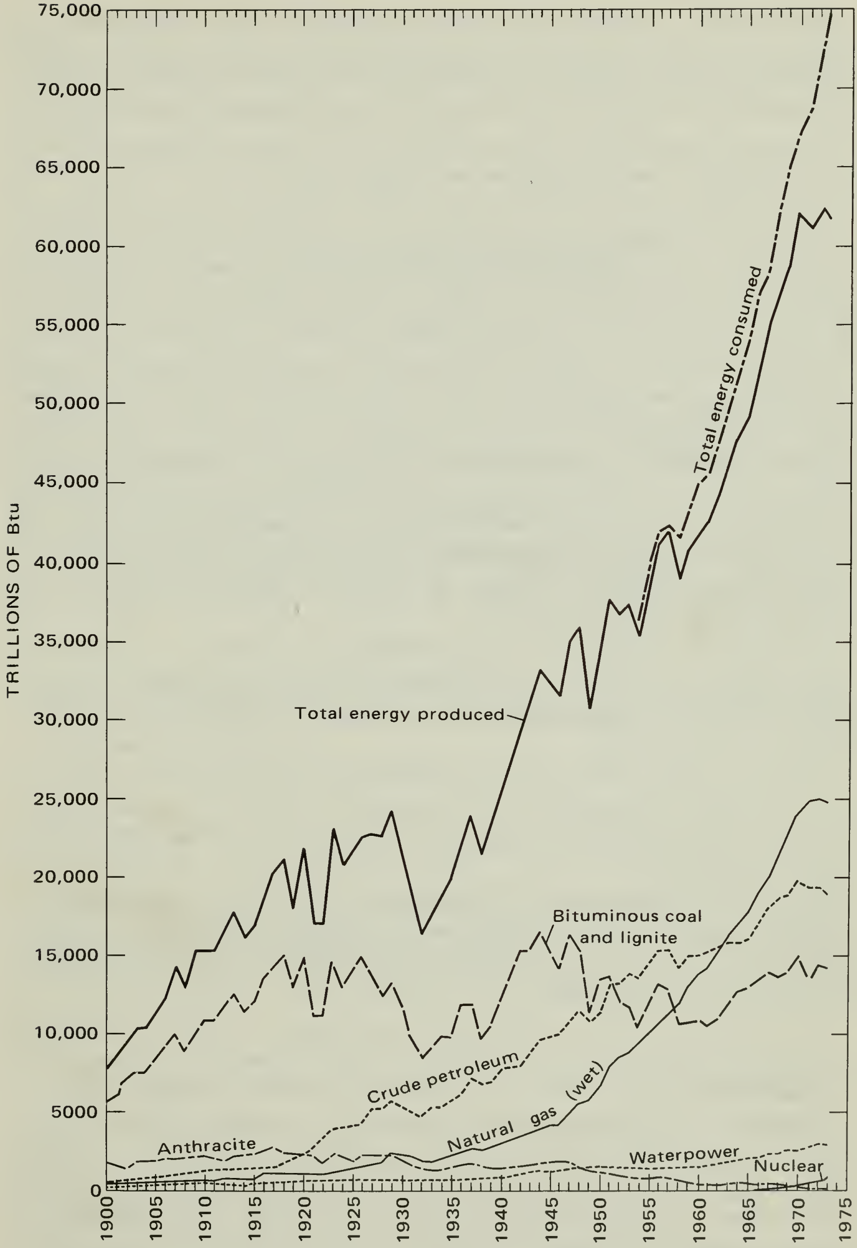



FIGURE 11.—Annual production and consumption of energy in the United States, 1900–73. (Source: U.S. Bureau of Mines Minerals Yearbooks 1963–73.)

With consumption of energy in progress on such an enormous and increasing scale, it is interesting and instructive to review the position of coal in the total energy pattern.

During 1972, a record year in the production and consumption of energy in the United States, coal supplied 23 percent of the energy produced and only 17 percent of the energy consumed, whereas petroleum and natural gas supplied 71 percent of the energy produced and 78 percent of the energy consumed. The remaining few percent of energy produced and consumed was supplied by waterpower and nuclear energy (U.S. Bureau of Mines Minerals Yearbook, 1972, p. 26).

As shown in figure 12, the percentage of annual energy production supplied by coal, including bituminous and subbituminous coal, lignite, and anthracite, has decreased steadily from about 90 percent in 1900 to the 1972 low of 23 percent. The percentage decrease in production of coal through the years has been accompanied by a corresponding percentage increase in production of petroleum and natural gas. This increase has occurred for a variety of reasons. Petroleum is a unique source of gasoline used in automobiles, kerosenelike oils used for jet fuels, diesel oils used in trucks and trains, heavy oils used in road construction and maintenance, and lubricants. Petroleum, residual crude, and natural gas have also had great consumer appeal for household heating, and for the generation of electric power, because of their convenience, cleanliness, and, until recently, relatively low price.

As shown in figure 12, the percentage contribution of domestic production of petroleum to total domestic energy production reached a peak in 1954, and actual production, as shown in figure 11, may have reached a peak in 1970.

Figures 11 and 12 also show an apparent leveling in the early 1970's of actual domestic production of natural gas and of the percentage contribution of domestic production of natural gas to total domestic energy production.

If peaks, or interim peaks, of annual domestic production of petroleum and natural gas have been reached, two important relations between price and supply and between price and demand remain to be tested during the late 1970's and early 1980's.

The decrease in the percentage contribution of coal to the total production of energy in the United States has not been accompanied by a comparable decrease in the actual production of coal (fig. 11). More accurately, the production of coal leveled off at the end of World War I, and for most subsequent years has fluctuated between 400 million and 600 million tons. The lowest recorded production was in 1932, when only 360 million tons was mined, and the highest was in 1947, when 688 million tons was mined (U.S. Bureau of Mines Minerals Yearbook, 1964, p. 49, 187). Between 1970 and 1973 annual coal production ranged from 571 million to 616 million tons. The position of coal in the industrial economy is bolstered by (1) its increased use in the production of electricity and in the manufacture of steel (p. 77); (2) steady export demand

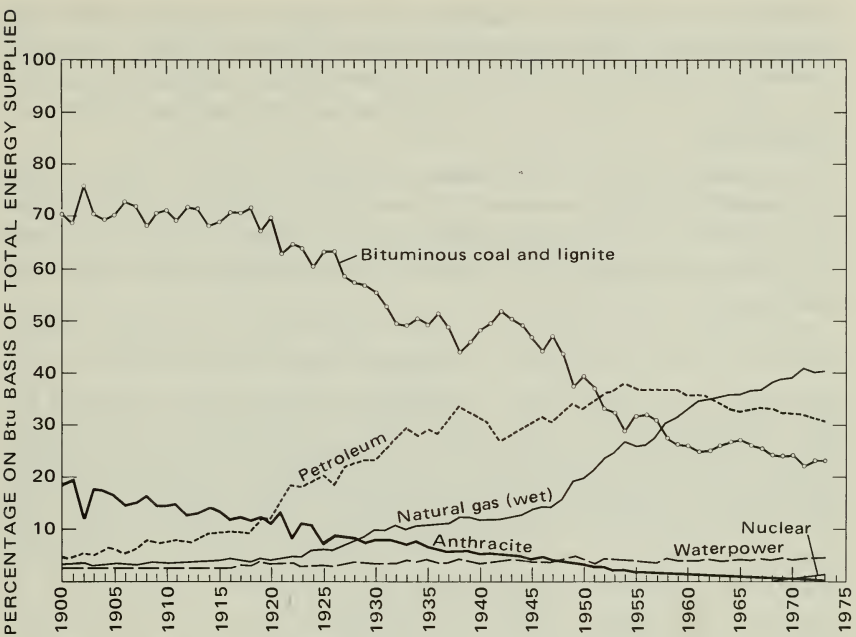



FIGURE 12.—Percentage of annual United States production of energy supplied by mineral fuels, waterpower, and nuclear power, 1900–73. (Source: U.S. Bureau of Mines Minerals Yearbooks, 1965, 1969, 1973.)

(p. 79); and (3) its potential value as a source of synthetic gas and liquid fuels (p. 82).

Concomitant with these major trends in domestic production has been a steady increase in imports of petroleum and petroleum products, beginning in the mid-1950's. The increased dependence on such imports is reflected in figure 11 as a widening gap between energy produced and energy consumed.

## PROBLEMS OF COMPARING ESTIMATES OF FOSSIL-FUEL RESOURCES

Estimates of resources of coal, oil shale, and bituminous sandstone cannot be compared readily with estimates of petroleum and natural gas, because the two kinds of fuel occur in different environments, and resources of each kind are calculated in different ways.

Coal, oil shale, and bituminous sandstone occur in stratified deposits that are near the surface and are readily visible in outcrops in most parts of the United States. The gross distribution of rocks containing these deposits has been known for many years.

Because coal occurs in lens-shaped bodies of fairly uniform breadth and

thickness, estimates of the total quantity in the ground can be made with reasonable accuracy through use of detailed information on the thickness, number, and continuity of coal beds at the outcrops and through general knowledge of the thickness, areal distribution, and structure of the coal-bearing rocks.

The total resources of bituminous sandstone and oil shale can be estimated with similar accuracy because these substances also occur in lens-shaped or tabular bodies that can be studied at the surface and because the thickness, areal distribution, and structure of the enclosing rocks are also well known.

Petroleum and natural gas, on the other hand, are highly mobile substances. Originally present as widely disseminated minute globules in sedimentary rocks, they move underground through pore spaces in the rocks and accumulate only where traps or barriers prevent further migration. Because a great variety of subsurface structural and stratigraphic relations create such traps, the total number of traps existing in the widespread, thick sequences of sedimentary rock in the United States cannot be predicted accurately, nor can the amount of ultimately recoverable petroleum and natural gas contained in these traps be ascertained. In many respects, the ultimately recoverable resources of petroleum and natural gas in the United States are determined by an ever-improving technology in methods of exploration, drilling, and recovery. In 1972, for example, wells 30,000 feet deep were entirely practicable, whereas only 30 years earlier the limit was about 12,000 feet. Comparable improvements have been made in primary, secondary, and even tertiary recovery practices.

Because petroleum and natural gas deposits are hidden deep below the surface, only minimum proved reserves in developed areas can be estimated with acceptable accuracy. For this reason, past estimates of total resources of petroleum and natural gas have been based primarily on trends in estimates of proved reserves and on the existing technology. Consequently, the past estimates for total recoverable resources of petroleum and natural gas tended to be conservative, and they had to be increased frequently to accord with new discoveries and with improved methods of drilling and recovery.

In recent years, the amount of subsurface geologic information has increased progressively through intensive drilling and interpretation, and recent estimates of total resources of petroleum and natural gas have been based on a more sophisticated analysis of the total volume of favorable rock, trends of deposition, number and position of unconformities in the stratigraphic succession, and other objective factors. As a result, estimates of total resources of petroleum and natural gas have steadily improved in accuracy and value.

Despite the recognized difficulty in comparing resource estimates of the several fossil fuels, it is possible to show the approximate relative

magnitude of these resources as currently estimated by converting estimates to their total heat-value equivalents, and by making minor adjustments to allow for differences in parameters, methods, or points of view used in making calculations.

The estimated remaining recoverable resources of the several fossil fuels as of January 1, 1974, are thus presented in table 10. The table gives the resource information in standard units of measure, in quadrillions ($10^{15}$) of Btu, and as a percentage of the total on a Btu basis. The table also gives the resource information under two headings, termed "Reserves" and "Total Resources," as defined in the table and in subsequent paragraphs.

## RESERVES

Reserves, as presented in columns 1-3 of table 10, include fuel comparable in thickness, quality, reliability, or accessibility to that recovered under the economic conditions prevailing on January 1, 1974. The sources of the figures used, and their conservative nature, are explained in the accompanying footnotes.

## TOTAL RESOURCES

Total resources, as presented in columns 4, 5, and 6 of table 10, include all the material in columns 1, 2, and 3, plus much larger quantities of material of marginal or submarginal grade that is estimated to be available for future use as needed. The larger amount of marginal or submarginal material will probably be recovered only at higher costs, expressed in man-hours and materials, than at present, but these costs may be reduced by future improvements in technology. The source and nature of these estimates are also explained in the accompanying footnotes.

The figures for coal in columns 4, 5, and 6 omit all coal in thin beds and all coal more than 3,000 feet below the surface. With this adjustment, the figures for coal should be reasonably comparable to figures for other resources of fossil fuel. In any event, it is unlikely that coal in thin beds or in the centers of deep structural basins will be needed in the foreseeable future.

The figures for total resources of petroleum and natural gas used in columns 4, 5, and 6 of table 10 are for the 48 conterminous States, Alaska, and the adjoining continental shelves of both areas to a water depth of 200 metres. They are based on an assumed recovery of 32 percent and on 1974 prices and technology (U.S. Geological Survey, 1975). The cited statement includes estimates in several categories according to the abundance and reliability of data, and the figures selected for the purpose of this comparison are the highest of those presented.

Other estimates of total potential resources of petroleum and natural gas, published by the American Association of Petroleum Geologists

TABLE 10.—*Comparison between remaining recoverable resources of coal and other fossil fuels in the United States, January 1, 1974*

[Neg., negligible]

| Mineral fuel | Reserves[1] | | | Total resources[2] | | | Production |
|---|---|---|---|---|---|---|---|
| | Standard units of measure[3] (1) | Quadrillions ($10^{15}$) of Btu[4] (2) | Percent according to Btu content (3) | Standard units of measure[3] (4) | Quadrillions ($10^{15}$) of Btu[4] (5) | Percent according to Btu content (6) | 1973 (quadrillions ($10^{15}$) of Btu[4]) (7) |
| Coal | [5]217 | 4,900 | 80 | [6]1,038 | 21,400 | 69 | 15 |
| Petroleum and natural gas liquids | [7]44.4 | [8]246 | 4 | [9]234 | [8]1,298 | 4 | 22 |
| Natural gas (dry) | [10]259.6 | 268 | 4 | [11]1,095 | 1,129 | 3 | 25 |
| Oil from oil shale | [12]125 | 725 | 12 | [13]1,234 | 7,157 | 23 | Neg. |
| Bitumen from bituminous sandstone | [14]2.5 | 14 | Neg. | [15]15 | 87 | Neg. | Neg. |
| Total | .... | 6,153 | 100 | .... | 31,071 | 99 | 62 |

[1]Portion of total resource that can be extracted economically and legally as of January 1, 1974.

[2]Identified and hypothetical resources, January 1, 1974. Includes data in reserve category in columns 1, 2, and 3.

[3]Coal in billions ($10^9$) of short tons; petroleum, natural-gas liquids, oil from oil shale, and bitumen from bituminous sandstone in billions of barrels of 42 U.S. gallons; and natural gas in trillions ($10^{12}$) of cubic feet.

[4]Figures in columns 1, 4, and 7 coverted to Btu according to the following heat values: Anthracite, 12,700 Btu per pound; bituminous coal, 13,100 Btu per pound; subbituminous coal, 9,500 Btu per pound; lignite, 6,700 Btu per pound; petroleum, oil from oil shale, and bitumen from bituminous sandstone, 5,800,000 Btu per barrel; natural-gas liquids, 4,100,000 Btu per barrel; and natural gas 1,031 Btu per cubic foot.

[5]Demonstrated reserve base, January 1, 1974, of 434 billion tons; less 50 percent to allow for estimated losses in mining for a remainder of 217 billion tons. Estimate by U.S. Bureau of Mines (1974b).

[6]Remaining identified and hypothetical resources, January 1, 1974, of 3,580 billion short tons to a maximum overburden depth of 3,000 feet from table 3; less 42 percent to eliminate estimated tonnage in thin beds (fig. 5*D*) for a remainder of 2,076 billion tons; less 50 percent to allow for estimated losses in mining for a remainder of 1,038 billion tons.

[7]Measured reserves, January 1, 1975, of 40.6 billion barrels plus estimated 1974 production of 3.8 billion barrels for a total, January 1, 1974, of 44.4 billion barrels. Estimate by U.S. Geological Survey (1975).

[8]Btu content calculated on assumption that 15 percent of the reported recoverable reserves and total resources will be natural gas liquids.

[9]Measured reserves, January 1, 1974, of 44.4 billion barrels from column 1, plus indicated and inferred reserves of 40.6 billion barrels, and undiscovered resources of 149 billion barrels for a total of 234 billion barrels. Estimates by U.S. Geological Survey (1975).

[10]Measured reserves, January 1, 1975, of 237.1 trillion cubic feet, plus estimated 1974 production of 22.5 trillion cubic feet for a total, January 1, 1974, of 259.6 trillion cubic feet. Estimate by U.S. Geological Survey (1975).

[11]Measured reserves, January 1, 1974, of 259.6 trillion cubic feet from column 1, plus inferred reserves of 180 trillion cubic feet, and undiscovered resources of 655 trillion cubic feet for a total of 1,095 trillion cubic feet. Estimates by U.S. Geological Survey (1975).

[12]Original identified resources of 418 billion barrels (oil yield) in oil shale beds in the Green River Formation, Colo., Utah, and Wyo., in zones at least 100 feet thick, yielding 25–100 gallons per ton and averaging about 30 gallons per ton; less 70 percent to allow for losses in mining and processing for a remainder of 125 billion barrels. Estimate by Culbertson and Pitman (1973).

[13]Original identified and hypothetical resources of 2,468 billion barrels (oil yield) in oil shale beds in the Green River Formation, Colo., Utah, and Wyo.; less 50 percent to allow for losses in mining and processing for a remainder of 1,234 billion barrels. Includes material of marginal grade as low as 10 gallons per ton. About 20 percent of the total ranges in grade from 25 to 100 gallons per ton and averages about 30 gallons per ton. About 80 percent ranges in grade from 10 to 25 gallons per ton and probably averages about 15 gallons per ton. Estimate by Culbertson and Pitman (1973). Culbertson and Pitman record large additional potential shale oil resources in the Chattanooga Shale of the Central and Eastern United States, and in marine shales of Alaska, but these resources are generally less well documented or are of generally lower grade than that accepted for use in this table.

[14]Original identified resources of 5 billion barrels (oil yield) in deposits at Edna, Calif.; Asphalt Ridge and P.R. Springs, Utah; and Uvalde, Tex.; less 50 percent to allow for estimated losses in recovery for a remainder of 2.5 billion barrels. Estimate based on resource figures compiled by Cashion (1973).

[15]Original identified and hypothetical resources in known larger deposits totaling about 29 billion barrels (oil yield); less about 50 percent to allow for estimated losses in recovery for a remainder of 15 billion barrels. Estimate based on resource figures compiled by Cashion (1973).

(1971); the National Petroleum Council (1972); and the Potential Gas Committee (1973), contain a wealth of detailed information on methodology of resource calculation, resource data on regions and States in the United States, and subsidiary data on costs of production and future energy demands. These reports, together with the previously cited U.S. Geological Survey report, go far beyond the limited specialized objective of table 10 and will be of great interest and value to anyone interested in these commodities.

The preponderance of coal in the total fossil-fuel reserve and total resource picture, as currently estimated, is clearly shown in columns 3 and 6 of table 10. In column 3, coal is seen to represent 80 percent of the estimated total reserves of the 5 fossil fuels; whereas petroleum, natural-gas liquids, and natural gas combined represent only 8 percent. In column 6, coal is seen to represent 69 percent of the estimated total resources of the 5 fossil fuels, whereas petroleum and natural-gas liquids, and natural gas combined represent only 7 percent.

Based as they are on estimates by different individuals working on different commodities from slightly different points of view, the calculated percentage figures obviously express a qualitative rather than an exact quantitative relation between the several kinds of fossil fuel. This should not detract from their interest and value.

In view of the relatively large resources of coal and the relatively small resources of petroleum and natural gas, it is instructive to consider the rates at which these fuels are currently being produced and consumed. In column 7 of table 10, the production of each fuel for the year 1973 has been converted to quadrillions of Btu. On this uniform basis it will be noted that the production of petroleum, natural-gas liquids, and natural gas combined is 3 times the production of coal. Thus, petroleum, natural-gas liquids, and natural gas, which represent 7 percent of the total fossil-fuel resources of the United States, are being used 3 times as fast as coal, which represents 69 percent of the total fossil-fuel resources. Continued dependency on petroleum and natural gas at the high levels witnessed in 1973 is certain to be impracticable and is likely to be impossible in the future.

## FUTURE USE OF COAL

As an abundant widespread source of heat and energy, coal is certain to be used in increasing quantities in the immediate future. It will share in long-term energy growth, and, in particular, it will contribute substantially to the generation of electricity and to the manufacture of synthetic liquid fuel and gas.

### INCREASE IN USE OF ENERGY

As shown in figure 11, an unprecedented fourfold increase in use of energy has taken place since the mid-1930's and use has doubled in the last

20 years. This increase is due in part to an increase in population and in part to an increase in the per-capita use of energy. It is difficult to project such a steeply rising trend far enough into the future to be meaningful, but any projection will yield results of very large magnitude. The U.S. Bureau of Mines (1970, p. 16) estimated that total energy use in the year 2000 will be in the range of 166 to 239 quadrillion Btu. The lower figure is 2.2 times the record 74.7 quadrillion Btu consumed in 1973. Even if growth in population and in the economy is slower in the future than in the past, continued increase in energy demand seems to be inevitable.

Any increase in total use of energy should result in an increase in use of coal and in previously unused or subordinate sources of energy.

## GENERATION OF ELECTRICITY

As noted previously (p. 77), the electric utility industry, which is the largest single consumer of coal, has increased its use of coal at a very rapid rate during the last 20 years. The utility industry is also a substantial consumer of other fuels. In 1972, when coal contributed 42 percent (expressed on a Btu basis) of the total energy consumed by the electric utility industry, dry natural gas contributed 22 percent; petroleum, 17 percent; hydropower, 16 percent; and nuclear power, 3 percent (U.S. Bureau of Mines Minerals Yearbook, 1972, p. 27–28).

The well-established trend toward increased use of coal by the utilities is likely to continue throughout the near term because of (1) the anticipated steady growth of the industry, (2) the recent construction and planned construction of coal-fired generating plants in areas previously served by natural gas, and (3) the gradual phase-out of older gas-fired generating plants.

### MAGNETOHYDRODYNAMIC (MHD) GENERATORS

Success in the development of the magnetohydrodynamic (MHD) generator could improve the efficiency of electric power generation and have a pronounced effect on use of coal for this purpose. The MHD generator has been the subject of continued research during the last decade in the United States, West Germany, the U.S.S.R., and Japan. In the MHD generator, a stream of high-temperature gas seeded with an alkaline salt to improve conductivity is forced at high velocity through a magnetic field, where electricity is generated directly without use of moving parts. Conceptually, the stream of hot gas replaces the revolving armature of a conventional generator.

In the early 1970's research on MHD generators, supported in part by grants from the Office of Coal Research, U.S. Department of the Interior, was in progress by the Aveco Corp., Gilbert Associates, Inc., Stanford University, STD Research Corp., University of Tennessee Space Institute, U.S. Bureau of Mines, Westinghouse Electric Corp., and others.

A parallel research objective is development of an innovative, three-stage generating plant in which the first stage is a coal gasification plant, the second stage, an MHD generator, and the third stage, a conventional generating plant fueled by the still hot, combustible exhaust gas from the MHD generator. (See Bergman and others, 1973.)

The most attractive features of a three-stage generating plant are the possible higher levels of thermal efficiency and prospective lower levels of emission of $SO_2$ and particulate matter.

## MANUFACTURE OF SYNTHETIC LIQUID FUELS AND GAS

Methods of gasifying and liquefying coal have been known for many years. Throughout the 19th century "coal gas" was used extensively in London and other large cities in Great Britain for street lighting and household heating, and "coal oil" was used in rural areas. This usage quickly spread to the Eastern United States and continued on a substantial scale until natural gas became generally available. In World War II the German military machine was fueled in substantial part by synthetic gasoline made from brown coal by the then newly developed Lurgi process. This process, with minor improvements, is in use in at least 58 plants throughout the world; 13 Lurgi plants are in operation in South Africa alone. The first coal gasification plant scheduled to be built in the United States in the late 1970's will be a Lurgi plant in New Mexico.

The initial cost of a Lurgi plant is high, and it requires carefully sized noncaking coal. Intensive research on improved methods of producing both low-Btu and high-Btu gas from coal, sponsored in considerable part by the Office of Coal Research (1972, 1973, 1974), has been in progress in the United States for more than a decade. Several methods that proved to be successful in the pilot stage are now in the demonstration-plant stage. If the Lurgi gasification plant is regarded as a first-generation plant, then one or more of the improved methods now in the demonstration-plant stage will be the basis of the second-generation coal gasification plants that will be built in the United States in the early 1980's.

Plans to build large-scale commercial coal gasification plants have been announced by several corporations; among them are El Paso Natural Gas Co., San Juan County, N. Mex., and Dunn, Stark, and Bowman Counties, N. Dak.; Western Gasification Co., a partnership between Texas Eastern Transmission Co. and Pacific Lighting Co., San Juan County, N. Mex.; Natural Gas Pipeline Co. of America, Dunn County, N. Dak.; Michigan-Wisconsin Pipeline Co., Mercer County, N. Dak.; Wyoming Coal Gas Co. and Rochelle Coal Co., Campbell and Converse Counties, Wyo.; Texaco, Sheridan County, Wyo.; Cameron Engineers, Adams and Arapahoe Counties, Colo.; and Texas Gas Transmission Corp., western Kentucky.

From data available on the announced plants in this representative list,

it is obvious that even with major changes in plans and shifts of interest, several Lurgi gasification plants will be in operation in the United States by 1980; also, about 10 additional second-generation gasification plants will be in operation in the mid-1980's.

The direct liquefaction of coal is a parallel line of investigation that has proved to be successful in several pilot-plant experiments. In this approach to coal conversion, pulverized coal is mixed in a slurry with a byproduct oil obtained as part of the process. The mixture is then hydrogenated at various temperatures and pressures to obtain a liquid hydrocarbon. The method is promising because (1) removal of ash and sulfur from the liquid is greatly simplified; (2) the conversion efficiency is about 75 percent as compared with 60 percent for coal gasification; (3) less water is required for the conversion; and (4) the final product is a high-Btu, clean-burning heavy liquid that can be further hydrogenated to obtain gasoline or light oils.

In January 1975 the Office of Coal Research signed a $237 million contract with the Coalcon Co.—a subsidiary of the Union Carbide Corp.—and the Chemical Construction Co. for the design, construction, and operation of a demonstration coal-hydrogenation plant designed to convert high-sulfur coal to low-sulfur liquids and gas. The plant, to be financed jointly by the Office of Coal Research and the Coalcon Co., will be of an intermediate size. As currently planned, the plant will process 2,600 tons of coal per day and yield 3,900 barrels of synthetic crude oil and 22 million cubic feet of pipeline-quality gas per day. The plant is scheduled for completion in 1979 (Coal News, 1975).

## CONCLUSIONS

In the changing pattern of energy consumption, coal has an assured position throughout the forseeable future because of its abundance, widespread distribution, and chemical versatility.

The past history of the coal industry (p. 60) was characterized by intense competition with petroleum and natural gas, in which these fuels captured the railroad and household markets and made great inroads into the utility, cement, and manufacturing markets. Nevertheless, coal production remained fairly constant in the general range of 400 million to 600 million tons annually. Since 1961, when an interim low of 420 million tons was recorded, coal production has increased steadily, and it is unlikely that this low will recur in the foreseeable future.

The increased coal production since 1961 has been used primarily by the electric utility industry. Converted to electricity, coal is indirectly recapturing part of the household market lost years ago to petroleum and natural gas because of the great increase in household use of electricity for light, air conditioning, radios, television sets, and other appliances.

As the future unfolds, it is certain that the amount of coal used in the manufacture of coke and byproduct chemicals will increase at a rate

commensurate with growth in the gross national product, and that coal used in the generation of electricity will increase at least to the year 2000, by which time nuclear energy will probably furnish about half the total electric generating capacity of the United States. In the year 2000, coal will probably be responsible for the remaining half of electric-generating capacity in coal-fired plants already constructed and planned for construction in the immediate future.

Beyond the year 2000, the future of coal in the generation of electricity becomes less predictable, but much coal will still be used in older, highly efficient coal-burning plants in and near coal fields and in small plants serving small communities. The future of coal in the generation of electricity hinges mainly on the success of research to perfect breeder and fusion reactors that will contribute permanently to supplies of nuclear fuel and on the success of research to capture solar, wind, tidal, and other alternate sources of electric power. The rapid pace of technologic development in the energy field suggests that beyond the year 2000 coal will be gradually phased out of the electric utility market.

While this transition is taking place, coal, as a remarkably versatile high-Btu chemical compound, is certain to become a major source of synthetic gas, liquid fuels, and lubricants, as well as a source for thousands of hydrocarbon compounds used by the manufacturing industries. When coal begins to take over this market, now served primarily by petroleum and natural gas, the demand for coal will be enormous and will more than compensate for the gradual loss of the electric utility market.

## GLOSSARY OF COAL-RESOURCE TERMS

**Resources.**—Total quantity of coal in the ground within specified limits of bed thickness and overburden thickness. Comprises identified and hypothetical resources.

**Original resources.**—Resources in the ground before the advent of mining.

**Remaining resources.**—Resources remaining in the ground as of a stated date. Obtained by subtracting production and estimated losses in mining from original resources, or by eliminating mined-out areas as of a stated date in preparing estimates of remaining resources.

**Identified resources.**—Combined tonnage in the measured, indicated, and inferred resource categories as defined below. All coal in the identified category is further classified according to rank, thickness of beds, and thickness of overburden.

**Measured resources.**—Tonnage of coal in the ground based on assured coal-bed correlations and on closely spaced observations about one-half mile apart. Computed tonnage judged to be accurate within 20 percent of the true tonnage.

**Indicated resources.**—Tonnage of coal in the ground based partly on specific observations and partly on reasonable geologic projection. The points of observation and measurement are about 1 mile apart but may be 1½ miles apart for beds of known continuity.

**Demonstrated resources.**—Combined tonnage in the measured and indicated resource categories as defined above.

**Inferred resources.**—Tonnage of coal in the ground based on an assumed continuity of coal beds downdip from and adjoining areas containing measured and indicated

resources. In general, inferred coal lies 2 miles or more from outcrops or from points of precise information.

**Reserve base.**—A selected portion of coal in the ground in the measured and indicated (demonstrated) category. Restricted primarily to coal in thick and intermediate beds less than 1,000 feet below the surface and deemed to be economically and legally available for mining at the time of the determination.

**Recoverability factor.**—The percentage of coal in the reserve base that can be recovered by established mining practices.

**Reserve.**—Tonnage that can be recovered from the reserve base by application of the recoverability factor. May be termed the "recoverable reserve."

**Identified-subeconomic resources.**—Tonnage in the identified category minus tonnage in the reserve base. Some of this remaining tonnage may be reclassified and added to the reserve base at a later date as a result of improved information or changed economic and legal conditions.

**Hypothetical resources.**—Estimated tonnage of coal in the ground in unmapped and unexplored parts of known coal basins to an overburden depth of 6,000 feet; determined by extrapolation from nearest areas of identified resources. Not otherwise classified. Future exploration to determine thickness, continuity, and quality of beds, and a more accurate estimate of tonnage will permit reclassification as identified resources. If data permit, some tonnage may be reclassified and added to the reserve base.

**Speculative resources.**—A category for discussion of possible areas of coal occurrence outside known United States' coal fields and coal basins as currently defined for coal resource studies; for example, (1) coal more than 6,000 feet below the surface in deep Rocky Mountain coal basins, and (2) coal on the continental shelves. No estimate was prepared for coal in this category.

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